LAKE SUPERIOR MEETING

AUGUST, 1920

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS

ORGANIZED 1871

INCORPORATED 1905

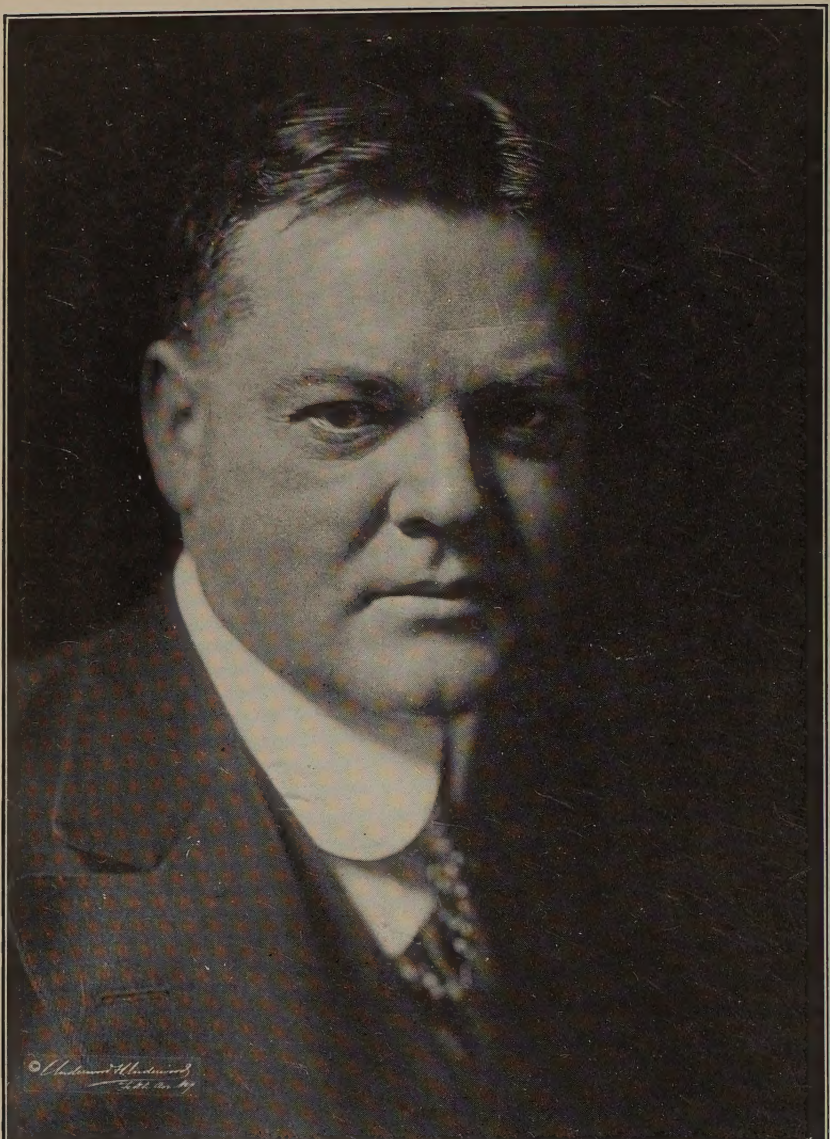
LAKE SUPERIOR MEETING

AUGUST, 1920

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS

ORGANIZED 1871

INCORPORATED 1905



HERBERT HOOVER

PRESIDENT OF THE AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS

HANDBOOK OF MINING

IN THE

LAKE SUPERIOR REGION

Prepared *for the* Lake Superior Meeting
of the American Institute *of* Mining
and Metallurgical Engineers
Held in August, 1920

SECTION ONE

By

ALEXANDER N. WINCHELL, D. Sc.
Professor of Mineralogy, University of Wisconsin

SECTION TWO

By

ENGINEERS CLUB OF NORTHERN MINNESOTA
and
DULUTH ENGINEERS CLUB

SECTION ONE

By

ALEXANDER N. WINCHELL, D. Sc.
Professor of Mineralogy, University of Wisconsin

SECTION TWO

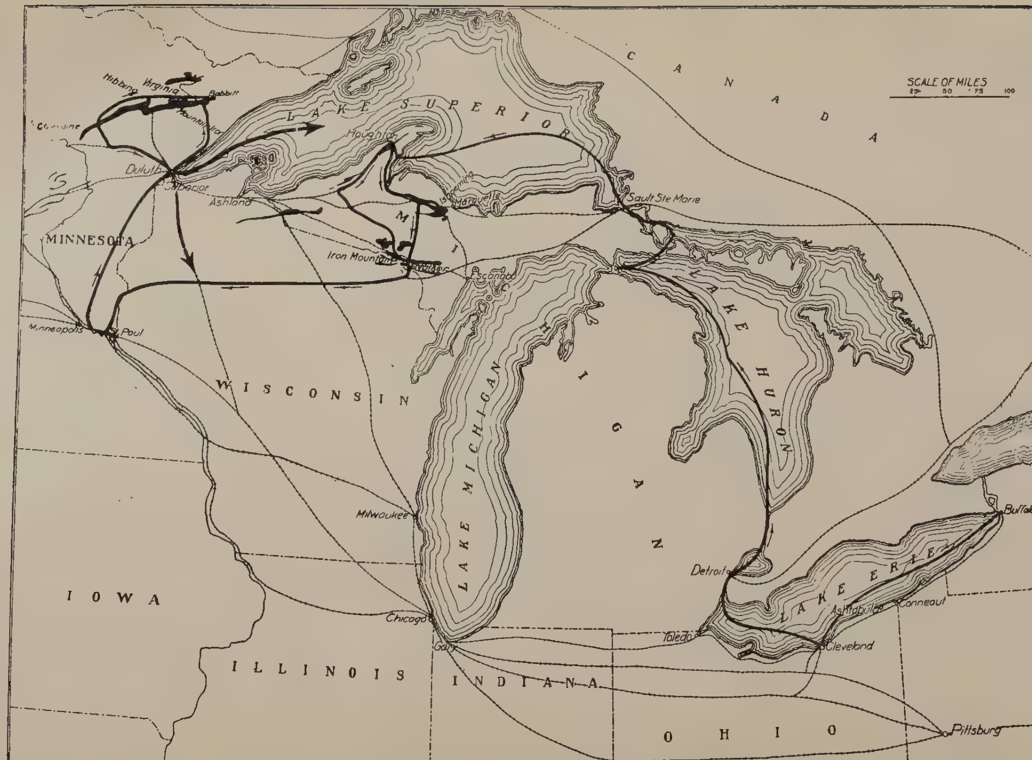
By

ENGINEERS' CLUB OF NORTHERN MINNESOTA

and

DULUTH ENGINEERS' CLUB

A Little Journey to Duluth and the
Minnesota Iron Ranges



Route of the Lake Superior Excursion of the American Institute of Mining and Metallurgical Engineers, August, 1920.

SECTION ONE

By

Alexander N. Winchell, D. Sc.
Professor of Mineralogy, University of Wisconsin

LAKE SUPERIOR MEETING
of
AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS

August, 1920

ITINERARY

Plans Subject to Change

Friday, August 20. Leave Buffalo, N. Y., on steamer "Tionesta" of the Great Lakes Transit Corporation, stopping at Cleveland, Detroit, Mackinac Island, and Sault Ste Marie.

Monday, August 23. Arrive Houghton, Mich., about noon. A trip is planned by automobiles to Lake Linden to see the Calumet and Hecla and Quincy stamp mills, the Calumet and Hecla smelter, electrolytic plant and leaching plant, returning to Houghton for supper and an evening dance at the Yacht Club.

Tuesday, August 24. At Houghton, Mich.

Morning: Visit surface plants of the mines about Houghton and Calumet. Those who desire to do so may go underground.

Afternoon: A trip (leaving Houghton about noon and returning before 6 p. m.) is arranged about 20 miles northeast of Calumet through the old Keweenaw mining district, with lunch at Eagle Harbor.

Evening: Dance at the gymnasium of the Michigan College of Mines. There may be a technical session at the College of Mines.

Leave Houghton at 11 p. m. on two special trains, one going to Ishpeming on the Marquette Range and the other to Vulcan, Norway, and Iron Mountain on the Menominee Range.

Wednesday, August 25. At Ishpeming, Mich.

Morning: About two hours will be spent at the Pioneer Charcoal and Iron Furnace, where not only pig iron and charcoal are made, but also many charcoal by-products, such as wood alcohol, formaldehyde, acetic acid, acetone, etc.

Or a trip may be taken to Marquette to see the reinforced concrete ore loading dock and the shops of the E. J. Longyear Company where diamond drill outfits and supplies are manufactured.

Noon: Lunch at the Wawonowin Golf Club.

Afternoon: Visit the Athens mine where water is raised 2,500 feet in one lift by electric pumps. Other notable features include a concrete lined shaft, reinforced concrete head-frames, etc.

Wednesday, August 25. At Norway, Vulcan and Iron Mountain.

Morning at Vulcan and Norway: The Aragon mine at Norway is equipped with electric pumps, raising water 1,300 feet in one lift. The Penn Company's mines at Vulcan have complete electric equipment with automatic safety devices and electro-hydraulic shovels.

Afternoon at Iron Mountain: The Chapin mine has elaborate electric equipment, including pumps with a lift of 1,000 feet. The Pewabic mine is operated by electric power from a hydro-electric installation at Big Quinnesec Falls owned by the Oliver Iron Mining Company. The Section Six mine can produce large amounts of ore by open pit methods.

Evening: Technical session at Iron Mountain after arrival of both special trains. Leave late in the evening for Minneapolis.

Thursday, August 26. At Minneapolis, Minn.

Morning: Technical session at the Mining Building of the University of Minnesota. Sight-seeing trips for the ladies.

Noon: Lunch at Town and Country Club.

Afternoon: Sight-seeing trips.

Evening: Banquet and addresses at the Hotel Radisson. Leave on special trains for Mesabi Range.

Friday, August 27. Mesabi Range.

Morning: At Babbitt to inspect the new mine, concentrating and sintering plant of the Mesabi Mining Company. Thence to Virginia to see the 300-ton steam shovels. Thence

by automobile through Mountain Iron, where the Brunt ore drying plant is located, to Hibbing near the close of the day.

Evening: Business and social session at Hibbing.

Saturday, August 28. Mesabi Range and Duluth.

Morning: Inspection of the great iron ore washing plant at Coleraine.

Afternoon: Arrive at Duluth about 1 o'clock. Visit the Minnesota Steel Company's plant with its model village. Visit also the famous ore docks, grain elevators, etc. Drive around the boulevard on the heights overlooking the city and harbor. A trip is also planned through the harbor and up the St. Louis River to Fond du Lac, seeing again the different shipping facilities of the port, the second largest in tonnage in the United States. There will be music and dancing on board the vessel making the harbor trip.

A special train will leave Duluth for Chicago on Saturday evening, August 28.

Accommodations have been provided on the steamer "Juniata," leaving Duluth, August 30, and arriving at Buffalo, September 3, for those who wish to return by way of the Great Lakes.

Relief Map of the Lake Superior Region, showing the larger topographic features.

INTRODUCTION AND ACKNOWLEDGMENTS

The following description of the mining activities of the Lake Superior district was prepared in the midst of other regular duties during May and June, 1920. The time available was so limited that little more than a compilation of published material was possible. It is, therefore, to be understood that such sources were used in the fullest possible measure, the reports of the United States Geological Survey, the Michigan Geological Survey and the Minnesota Geological Survey being especially employed. In addition to these, numerous valuable descriptive articles have appeared in the proceedings of the Lake Superior Mining Institute, the transactions of the American Institute of Mining and Metallurgical Engineers, and in the mining periodicals, including the Iron Trade Review, the Iron Age and the Engineering and Mining Journal. All these have been freely consulted.

But this publication would have fallen far short of its aim without the active and cordial co-operation of many of the engineers of the district. Indeed, in some cases parts of the text have been contributed by these engineers, especially those parts relating to the descriptions of individual mines and the details of engineering features, etc. Local committees have also supplied many of the illustrations used freely throughout the book. For such invaluable assistance the writer is indebted, among others to the following contributors:

For the Michigan Copper district:

John Knox, Gen'l Supt., Calumet and Hecla Mining Company.

F. W. Denton, Vice Pres., Copper Range Company.

For the Marquette iron district:

M. M. Duncan, Vice President, Cleveland-Cliffs Iron Company.

For the Menominee iron district:

O. C. Davidson, Gen'l Supt., Oliver Iron Mining Company.

William Kelly, Gen'l Mgr., Penn Iron Mining Company.

For the Gogebic iron district:

Frank Blackwell, McKinney Steel Company.

W. O. Hotchkiss, State Geologist of Wisconsin.

For Minneapolis and St. Paul:

H. V. Winchell, Past President, A. I. M. E.
John E. Hodge, E. J. Longyear Company.
H. M. Roberts, Geologist.
Julius Segall, Geologist.

For the Cuyuna iron district:

Carl Zappfe, Geologist, Brainerd, Minn.

For the Mesabi iron district:

W. J. Olcott, President, Oliver Mining Company.
W. G. Swart, Gen'l Mgr., Mesabi Iron Company.
John U. Sebenius, Gen'l Mining Engr., Oliver Iron Mining Company, Duluth.

For Duluth:

Lieut. Col. F. A. Pope, Pres., Duluth Engineers' Club.

Finally, Professors R. S. McCaffery and E. R. Shorey, of the University of Wisconsin, have prepared important sections on metallurgy and mining, respectively, in the Lake Superior districts.

Those who wish further information regarding the Lake Superior region are referred to Monograph 52 of the U. S. Geological Survey, published in 1911, and to the bibliography in that volume (pages 73-84); for later articles and reports, see the annual volume published by the U. S. Geological Survey entitled, "Bibliography of North American Geology," Bulletins 495, 524, 545, 584, 617, 645, 665, 684, 698.

THE SOO CANAL.

The waters of Lake Superior flow into those of Lake Huron through the St. Mary's river. The rapids in this river are about half a mile wide and three-quarters of a mile long, in which distance the fall amounts to about twenty feet. Since this was the only obstacle to navigation between the west end of Lake Superior and ports on any of the other Great Lakes except Ontario, attempts were made many years ago to permit the passage of small boats from Lake Huron to Lake Superior by means of canals and locks. The first canal was built on the Canadian side of the river by the Northwest Fur Company in 1797-98. The lock was 38 feet long, 8 feet 9 inches wide and had a lift of 9 feet. A tow path was made along the shores for oxen to track the bateaux and canoes through the upper part of the rapids. The lock was destroyed during the war of 1812 by United States troops from Mackinac Island.

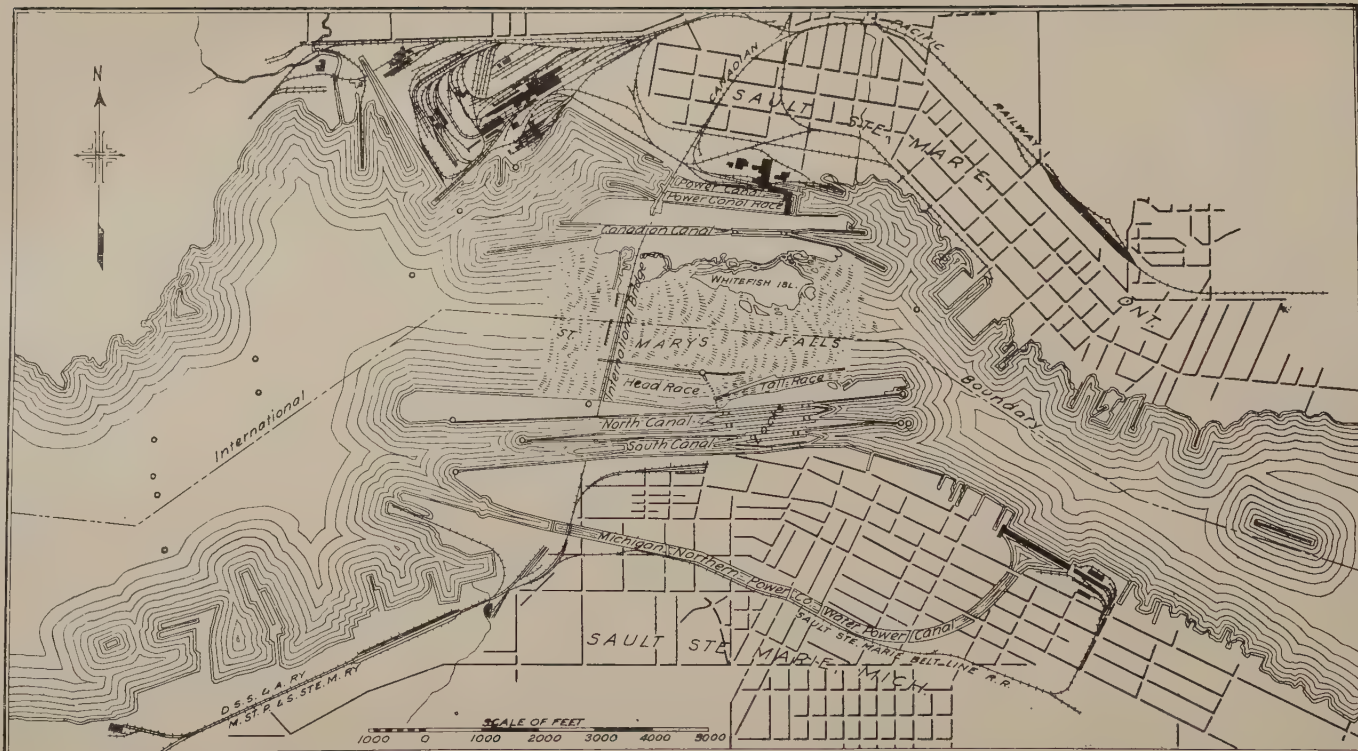
The first ship canal, known as the State Canal, was built on the American side of the river in 1853-55, about 750,000 acres of land in Michigan having been granted by congress to a private company as a concession for its construction. This canal was more than a mile long, 65 feet wide at the bottom and 100 feet wide at the water's surface. It had two locks, each 350 feet long by 70 feet wide, with a lift of about 9 feet. The depth of water in the canal was about 13 feet and in the locks about 11½ feet.

The Weitzel lock was built by the United States in the seventies. It is 515 feet long, 80 feet wide, and has a depth of 17 feet of water on the sills. During the same period the canal was correspondingly deepened and widened to 160 feet.

The Canadian canal, 1⅛ miles long, 150 feet wide, and 23 feet deep, with a lock 900 feet long and 60 feet wide and 22 feet of water on the sills, was built on the north side of the river in the years 1888 to 1895.

The Poe lock was built by the United States in the years 1887-1896. It is 800 feet long, 100 feet wide and has 22 feet of water on the sills.

The third lock, 1,350 feet long, 80 feet wide, was built in the years 1908 to 1914 by the United States Government and has more than 24 feet of water upon the sills even at low water.



Map of Sault Ste. Marie, Michigan, and Ontario, showing American and Canadian Canals and Locks.

The new fourth lock, of the same dimensions as the third lock, was built by the United States in the years 1913 to 1919, being opened to traffic on September 18, 1919.

Since 1892 the canal leading to the Weitzel and Poe locks has been deepened in its upper reach to 24 feet and the new canal leading to the third and fourth locks has a minimum depth of the same amount. The canal includes those parts of the channel through the St. Mary's river which have been improved by dredging through shoals of sand, clay and boulders, and even by removing solid sandstone and limestone. The United States made the first appropriation for improving the channel in 1858. The Lake George route was improved to a minimum depth of 12 feet between 1857 and 1869. About ten years later the depth was increased to 16 feet. The Hay Lake route was improved to a depth of 20 feet between 1882 and 1894. Improvement of the channels has been continued since that time so that the dredged areas now total 45 miles in length with a minimum width of 300 feet and a minimum depth of 24 feet.

Hydraulic power is used for operating the Weitzel and Poe locks and electricity generated by water power is employed in operating the third and fourth locks on the American side, and also the Canadian locks.

The American locks may be filled or emptied in about nine minutes and the gates may be opened in one and one-half minutes, but the average time spent in passing a boat through a lock last season was nearly thirty-two minutes, this difference being due to the slow movement of the boats while entering and leaving the locks and to the fact that in nearly half of the lockages more than one boat was passed. From 1855 to 1881 the canal was controlled by the State of Michigan and tolls were charged to cover operating and repair expenses. Since that date the American canal has been controlled by the United States and has been free for public use for all nations.

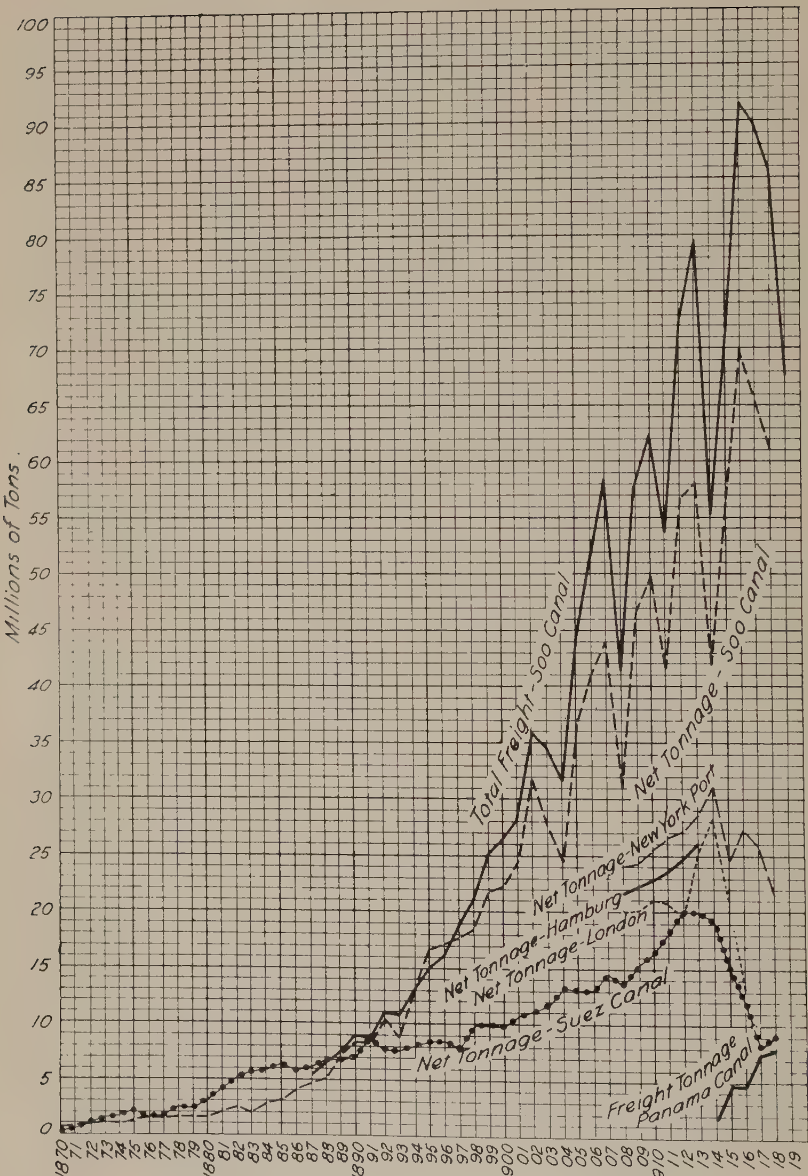
During the sixty-five years the canal has been in commercial use, the yearly traffic has increased from a minimum of 14,500 tons in 1855 to a maximum of 91,888,000 tons in 1916 with an average increase in tonnage each year over the preceding year of about 19 per cent. The relative tonnage passing through this canal as compared with that passing through other great canals of the world and that entering and leaving the greatest ports of the world is shown in the diagram on page 6 from 1870 to the present time, so far as statistics are available. It is clear from

Soo Canal and Locks. Upper approach looking west. International Bridge in the distance.

Soo Canal and locks. Lower approach looking west. October 11, 1915.

this diagram that the Soo Canal carries the greatest tonnage of any waterway in the world with the single exception, not shown on the diagram, of the tonnage passing through the Detroit river. It should be stated that the figures of tonnage used in the diagram are not strictly comparable, because "net tonnage" is calculated by rules which vary in the different ports, but it can be asserted with safety that if comparable figures were available the general results shown in the graph would not be materially modified. It should also be stated that the net tonnage of the great ports is exclusive of coast-wise trade; that is, it includes only tonnage entering from, or going to, foreign ports.

Compensating works at head of Rapids in St. Mary's River, Michigan, looking northwest from International Bridge, Jan. 24, 1919.



Tonnage at Soo Canal compared with other canals and with great ports.

THE MICHIGAN COPPER DISTRICT.

Location. The copper mines of Michigan are all in the northern part of that state on the Keweenaw Peninsula, which extends from the (Michigan) mainland for about seventy miles northeasterly toward the middle of Lake Superior. The mines occur in a belt or zone occupying the central portion of the peninsula from end to end. The most productive mines for many years past have been those located not far from the city of Houghton in the central part of the zone, in a section extending about ten miles southwest of Houghton and fifteen miles northeast. The most important mines in order of location, from the northeast to southwest, are the following: Mohawk, Ahmeek, Allouez, North Kearsarge, Wolverine, South Kearsarge, Centennial, Calumet and Hecla, Osceola, Franklin, Quincy, Hancock, Isle Royale, Superior, Baltic, Trimountain, and Champion. The first three named are in Keweenaw county and all of the others are in Houghton county. Still farther to the southwest are the Lake, Mass, Adventure, Michigan, Victoria, and White Pine mines. These are in Ontonagon county.

History. The exploitation of these copper mines extends back into prehistoric times. There is little evidence that the American Indians carried on mining operations in this region in the period shortly before the advent of white men, but there is abundant evidence that the ancestors of the Indians, or some earlier inhabitants of the region, carried on primitive mining operations. For example, Mr. S. O. Knapp, Agent of the Minnesota Mining Company, in the winter of 1847-48, made the first discovery of prehistoric mining. This event is described as follows by Foster and Whitney:

"Knapp came to a longitudinal cavern into which he crept. * * * He saw numerous evidences to convince him that this was an artificial excavation and at a subsequent day, with the assistance of two or three men, proceeded to explore it. In clearing out the rubbish they found numerous stone hammers, showing plainly that they were the mining implements of a rude race. At the bottom of the excavation they found a vein with ragged projections of copper, which the ancient miners had not detached; this point is east of the present works. The following spring he explored some of the excavations to the west, where one of the shafts of the mine is now sunk. The depression was twenty-six

feet deep, filled with clay and a matted mass of mouldering vegetable matter. When he had penetrated to a depth of eighteen feet he came to a mass of native copper ten feet long, three feet wide, and nearly two feet thick, and weighing over six tons. On digging around it the mass was found to rest on billets of oak supported by sleepers of the same material. This wood, specimens of which we have preserved, by its long exposure to moisture, is dark colored, and has lost all its consistency. The earth was so packed around the copper as to give it a firm support. * * * The ancient miners had evidently raised it about five feet and then abandoned the work as too laborious. They had taken off every projecting point which was accessible so that the exposed surface was smooth. Below this the vein was subsequently found filled with a sheet of copper five feet thick and of an undetermined extent vertically and longitudinally."

Many implements used by the prehistoric miners were found, including ten cartloads of stone hammers, a copper wedge, copper mauls and chisels, ladders formed of oak trees with the branches left projecting, wooden levers, etc.

The chief ancient mining operations were carried on at three points on the Peninsula. One of these points was a little below the forks of Ontonagon river, another at Portage Lake and the third on the waters of Eagle river. These ancient works were not always situated on good veins, but they were correctly regarded by the early explorers as good guides to the valuable lodes. Still other veins on Isle Royale and on the north shore of Lake Superior, opposite Keweenaw Point, were extensively worked in prehistoric times. It has been suggested that these mining operations were carried on by the Mound Builders, but it is still an open question whether the Mound Builders were the ancestors of the present American Indian, or belonged to a different race. Hemlock trees, showing three and four hundred annual growth rings, were found growing on some of the rubbish heaps of these old workings, and it is evident that the mines were abandoned not less than two or three hundred years before the discovery of America. The accounts of the early writers make it evident that the Indians knew nothing of the existence of these early mining works.

The first attempt at mining by white men was probably made by Alexander Henry, an Englishman, who came to America soon after the British obtained control of Canada. He heard of copper in the Lake Superior region and searched the coast of

the lake looking for mineral treasure in the years 1765-70. After many difficulties and only meager success, Henry found detached masses of copper on the Ontonagon river and spent about a year in searching for an important deposit in place. In 1774 the project was finally abandoned and for nearly seventy years thereafter the region remained a wilderness in which the existence of copper seems to have been almost forgotten. As stated by Past President Winchell,[1] "there were no explorations made of any sort looking toward the development of mining until Douglass Houghton was appointed state geologist of Michigan in March, 1838. * * * In his fourth annual report, submitted February 1, 1841, we find a discussion of the general prospects for profitable mining, including a description of the veins and a comparison of them with those of Cornwall, in which the statement is made that 'after as minute an examination of the substance as circumstances will permit, I am led to the conclusion that the only ores of the metallic minerals occurring in those portions of the veins which traverse the rocks last alluded to, which can be reasonably hoped to be turned to practical account, are those of copper.' * * * In a letter written by Dr. Houghton to Honorable Augustus Porter, member of Congress from Detroit, replying to an inquiry in the National Intelligencer, and dated December 26, 1840, we find substantial proof that he was not only acquainted with the location of some of the copper veins, but that he had actually gone into them and obtained native copper. His own statements are as follows:

"'The veins of ore traversing the mineral district of Lake Superior, in those portions I have examined closely, are of very frequent occurrence, and range from a few inches to fourteen feet in width. * * * I brought from Lake Superior on my return to Detroit this fall from four to five tons of copper ores and I am now busily engaged in making an analysis of them. Thus far they have proved equal to any ores I have ever seen, and their value for purposes of production can not be doubted. The average per cent of metal is considerably above that of the ores of Cornwall. While speaking of the ores, I am reminded of the beautiful specimens of native copper which came out with the ores in opening some of these veins. They are not very abundant, but some of them are very fine. In opening a vein, with a single blast I threw out nearly two tons of ore, and with this were many masses of native copper, from the most minute

[1]Proc. L. Sup. Mg. Inst., vol. 2, 1894, p. 42.

specks to about forty pounds in weight, which was the largest mass I obtained. Ores of silver occasionally occur with the copper. * * * I hope to see the day when, instead of importing the immense amount of copper and brass used in our country, we may become exporters of both.'

"Dr. Houghton did not mention in his annual reports the location of any of the veins which he discovered, with one exception, namely, that of the green silicate of copper at Copper Harbor. The land had not at that time been thrown open for settlement or even exploration, and he was undoubtedly reserving the details for publication in his final report, which he did not live to complete owing to his untimely death by drowning, in Lake Superior, during a snowstorm and gale near Eagle River, on August 13, 1845. His official report, however, called attention to the possibilities of the region; and the cession of the land to the United States by the Chippewas, which was ratified March 12, 1843, was the signal for the commencement of a speculative craze which lasted for three years, and completely justified the fears expressed by Dr. Houghton in anticipation."

Charles T. Jackson was one of the earlier explorers of the region, beginning his work in the summer of 1844. The first mines were not in the conglomerate in which the large mines are now chiefly located, "but in true fissure veins which crossed the conglomerate and interbedded amygdaloidal trap sheets in several systems. In these veins the copper (with a little silver) occurs in the native state in masses of all sizes up to a thousand tons. * * * "

Whitney speaks as follows of the discovery of the Cliff Mine, belonging to the Pittsburgh and Boston Mining Company: "The discovery and opening of this mine formed an era in the history of Lake Superior and are also of high interest to the country, as it was the first mine in the United States, those of coal and iron excepted, systematically and extensively wrought, and at the same time with profit. Besides this, it has a peculiar importance as being opened on a vein bearing copper exclusively in the native state, a feature entirely unknown in the history of mines previous to the discoveries on Lake Superior. * * * "

After the opening of the Cliff mine in the region of Eagle Harbor production continued at this time for fifty years. Only two years after its discovery, the Minnesota mine (now called the Michigan) was discovered by S. O. Knapp (in the year 1847), the discoverer being guided by depressions due to pre-

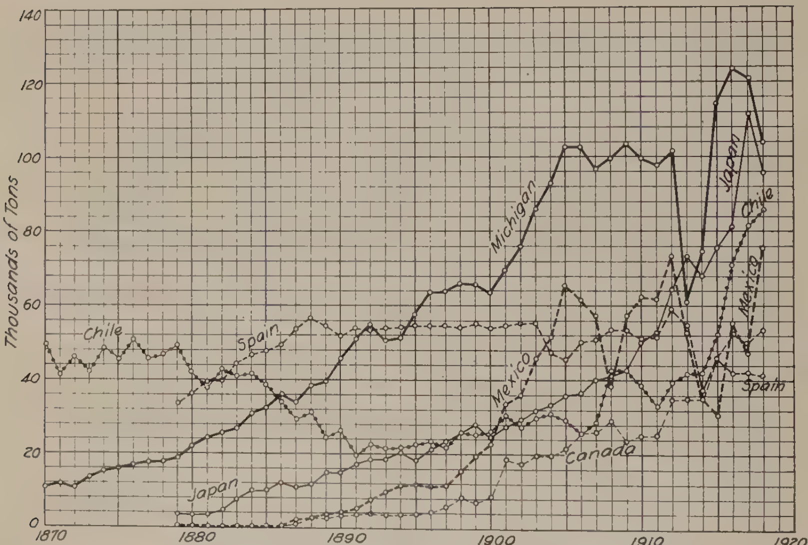
historic mining, as already described. The Minnesota mine, as well as the National, Mass, and other adjoining mines, first produced "mass-copper" from veins in the Keweenawan beds in Ontonagon county at the southwestern end of the district, but later copper was obtained in these mines from the amygdaloidal beds. Mass-copper forms at present only a small part of the output.

The next ores to be opened were the amygdaloid deposits in the central part of the district, which were first discovered in the Pewabic mine in 1848. The Quincy mine was opened in 1847, but the Quincy amygdaloid was not found until 1856, and the main Pewabic bed was found during the same year. The Portage lode was discovered in 1853 and Houghton was platted as a village in 1854. At this time the nearest railroad was at Green Bay, Wis. The first stamp mill erected was the Isle Royale in 1854, followed by the mill of the Portage Mining Company the next year. In 1877 the Osceola amygdaloid was discovered and the Osceola mine promptly became an important producer. The Wolverine mine began operations before 1890, but was not profitable until 1897. The amygdaloid deposits are now the most numerous and in 1918 produced a large proportion of the total copper ore of the district. The last discovery of a new type of copper ore in the district was that made in 1859 at the Allouez by E. J. Hulbert. This was the Allouez conglomerate which was worked for a short time, but soon proved unprofitable, at least in this locality. Later it was productive farther south on the Boston and Albany, the Peninsula and the Franklin Junior. About the first of September, 1864, Hulbert also discovered the Calumet and Hecla conglomerate which was opened in 1869. This discovery soon proved to be the most important in the district and the Calumet and Hecla Company has paid dividends aggregating $151,750,000 up to January, 1920, on an original capital of two and one-half million. More than a fourth ($41,200,000) of the total dividend payments of a half century were paid during the last decade.

Production. Michigan produced more copper than any other state in the Union for a period of forty years from 1847 to 1886, and for nearly the same length of time produced more than all other states combined. Since 1886 its production has continued to be very important, but is now exceeded by the production of Arizona and of Montana. However, the state of Michigan from the Keweenaw Peninsula has produced more

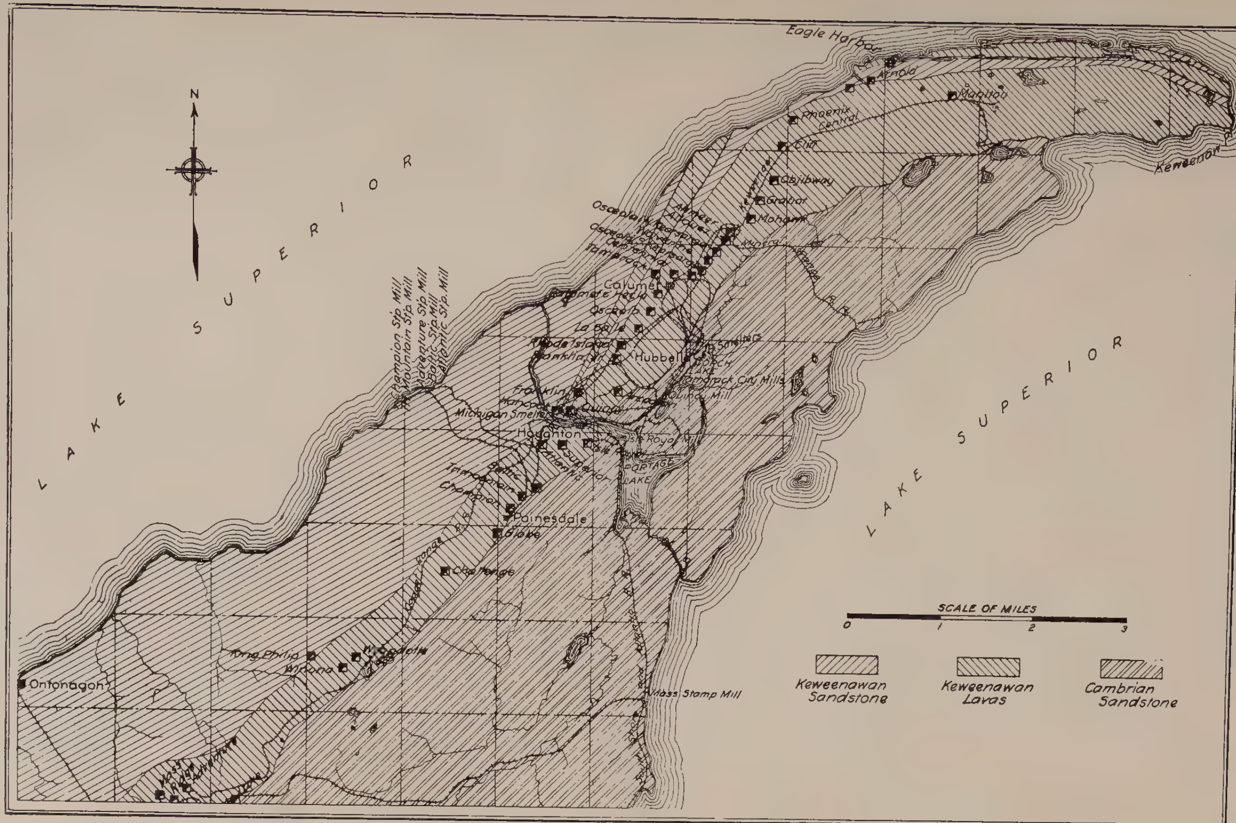
copper annually than any foreign country. This fact is brought out clearly in the graph of comparative production curves shown in Fig. below.

Geology. The copper ores of northern Michigan are found in rocks which are geologically very old, belonging to the series called Keweenawan, which antedates the oldest fossiliferous rocks of the region, that is, the Upper Cambrian. These Keweenawan rocks occupy a broad belt extending continuously from the Michigan-Wisconsin boundary along the south shore of Lake Superior to the eastern extremity of Keweenaw Point. The rocks occupy a zone varying from six miles in width at Keweenaw Point to nearly twenty miles in width west of Lake Gogebic.



Copper production of Michigan compared with that of the chief foreign producers, 1870-1920.

The general strike of the whole series is approximately parallel with the coast of Lake Superior, changing gradually from southeast at the end of the peninsula through east-west to N. 45 E., five to fifteen miles westward near the Wisconsin line. The whole series dips throughout the area to the north and northwest. In the southwestern portion of the area, the dip is steep, becoming gentler at the east end, where it is slightly less than 30 degrees. The lower beds dip in general at a higher angle than the upper ones, but this change in dip is gradual and does not imply an unconformity. The rocks of the Keweenawan series

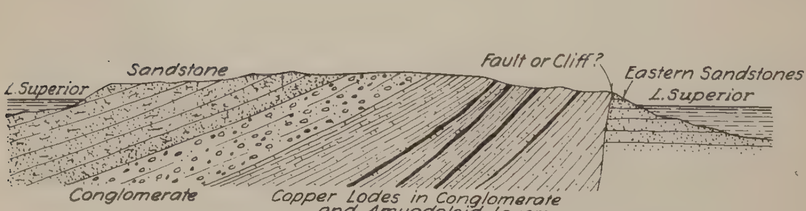


Map of Keweenawan Peninsula, Michigan, showing the geology and the location of mines, smelters and mills in the copper district.

have been divided into three parts, designated Upper, Middle and Lower. The last division includes a maximum of more than a thousand feet of sandstones and shales with very minor beds of light red limestone and a thin layer of basal conglomerate, but without interstratified lavas. This division is unknown in the region of the copper mines, and, accordingly, it is customary to speak of only two divisions of the Keweenawan (Upper and Lower) in this district. The Middle (or "Lower") Keweenawan rocks include some beds of sediments, but consist chiefly of diabasic lavas and other igneous rocks. The sediments vary from a few inches to a few feet in thickness, but in exceptional cases they are more numerous and attain a greater thickness. The igneous rocks are partly of the nature of surface flows and partly intrusive sills with occasional dikes. The Upper Keweenawan consists of red sandstones, shales and conglomerate, divisible into several members. The base is marked by a great conglomerate varying from three hundred to twelve hundred feet in thickness overlain by black shales of a maximum thickness of four hundred feet which are succeeded by red feldspathic sandstone attaining a thickness of nearly twenty thousand feet, and grading upward into more siliceous sandstone, red and green shales, and coarse arkose.

There has been a long discussion as to whether the Keweenawan formation antedates the Lower Cambrian or belongs to the Middle and Lower Cambrian.

The stratigraphic succession of the Keweenawan series of northern Michigan has been described as follows by Irving; it may be compared with the succession at the east end of Keweenaw Point as given by Hubbard.



Geological vertical section across Keweenawan Point.

Irving	Hubbard
12. Eastern sandstone, Keweenaw series. Upper division. 11. Red sanstone. 10. Black shale and gray sandstone ("Nonesuch belt").	
9. Red sandstone and conglomerate ("outer conglomerate"). Lower division.	Outer conglomerate.
8. Diabase and diabase amygdaloid, including at least one conglomerate belt ("Lake Shore trap").	Lake Shore trap (upper). Middle conglomerate. Lake Shore trap (lower).
7. Red sandstone and conglomerate ("Great conglomerate").	Great conglomerate.
6. Diabase and diabase amygdaloid, including several sandstone belts ("Marvine's 'Group C' of the Eagle River section"). 5. Diabase and diabase amygdaloid, including conglomerates. 4. Luster-mottled melaphyres and coarse-grained gabbros and diabases ("Greenstone group").	Ophites and porphyrites with interbedded conglomerates and sandstones.
3. Diabase, diabase amygdaloid, and luster-mottled melaphyre, including a number of conglomerate beds.	Melaphyres and interbedded conglomerates.
2. Quartz porphyry and felsite.	(a) Bohemia conglomerate. (b) Melaphyre. Locally Mount Houghton felsite replaces a and b. (c) Porphyrite and felsite porphyrite.
1. Diabase, diabase amygdaloid, melaphyre, diabase porphyry, and orthoclase gabbro, including also conglomerate beds and beds or areas of quartz porphyry and granitic porphyry ("Bohemian Range group").	Ophite belt. Lac la Belle conglomerate.

The central portion of the Keweenaw peninsula is occupied by a low plateau at an elevation of four hundred to six hundred feet above Lake Superior. From this long highland the ground slopes downward to the lake on both sides, gradually toward the northwest and more abruptly toward the southeast. The plateau is almost entirely cut in two by the narrow arm of Portage lake, which gives ready access for lake vessels. Farther to the northeast, the plateau drops away and there is a short gap of lowland followed by two long ridges which extend with occasional gaps to the end of the point. The northwestern ridge is called the Greenstone Range and the southeastern ridge is known as the Bohemian Range. The plateau and ridges are formed by the copper bearing rocks of the Middle Keweenawan. The northwestern slope of the plateau is formed by the overlying rocks of the Middle and Upper Keweenawan. The southeastern portion of the peninsula is occupied by nearly horizontal Upper Cambrian sandstones.

The geological structure of the copper district is simple in its major outline. The copper bearing rocks form the southern limb of a synclinal formation which dips under Lake Superior and appears again on the north shore. The dip of the formations commonly decreases with depth; for example, the dip of the copper lode at the Quincy mine near the surface is about fifty-four degrees, while it is only thirty-seven degrees at a depth of one mile, measured on the incline. At the Calumet and Hecla the change in dip is very slight, amounting to only two or three degrees in the same distance. At the Central mine the dip decreases from twenty-seven degrees at the surface to twenty-one degrees at the lower levels. Recent work in a few places has disclosed sharp folds in the formation, but these are only local and exceptional.

Faults are numerous and of several types in the Keweenawan series. The most important plane of movement is believed to be one nearly parallel with the strike where the whole formation has been brought up against the Upper Cambrian sandstone. Hubbard has estimated in another case that certain beds have moved nearly three miles almost horizontally along a plane approximately parallel with the strike. In many parts of the Keweenawan series thin beds of soft clay-like material have been found which were probably formed by extensive fault movements. In addition to these strike faults there are numerous planes of movement where faults cut across the bedding. In

such cases the displacement has been measured in many places and is usually small, rarely as much as one hundred feet, and commonly very much less. Such faults are specially numerous in the upper parts of the Keweenawan.

The common rocks of the copper district are dark gray and brownish lavas in beds or flows varying greatly in thickness, but commonly between ten and two hundred feet. Interbedded with these are reddish conglomerates and sandstones ranging from mere seams to beds of several hundred feet in thickness. Near the copper mines the sediments form only about seven per cent of the total thickness of the formation. Besides the dark colored volcanic rocks, there are some much smaller areas of light colored felsites and porphyrites and a few areas of more coarsely grained intrusive igneous rocks. Neither the coarse grained intrusives nor the felsites are found in the immediate vicinity of the copper mines.

The dark colored lavas vary only moderately in composition and character. The dense microcrystalline variety is commonly called trap, or melaphyre. It is often amygdaloidal in part, and such portions are commonly designated simply as amygdaloids. According to their textures, the melaphyres are classed as diabases, ophites and dolerites. Diabases show the lath shaped feldspars penetrating black augite crystals, while ophites show numerous lath shaped feldspars enclosed by single crystals of pyroxene, and dolerites are even grained and do not show the ophitic texture.

The Keweenawan rocks of the copper district are generally much altered. In some cases nearly all of the original minerals have been replaced by secondary products, the common secondary minerals being chlorite and epidote, with calcite, quartz, zeolites, etc., in some cases. The original cavities of the amygdaloids are ordinarily completely filled with these secondary minerals.

Nearly all of the copper mined in Michigan is obtained from the native metal. Copper occurs in compounds in Michigan, but to such a small extent that it is of no importance commercially. The native copper is found not only in veins, but also in bedded deposits consisting of conglomerates and of amygdaloids. Much more rarely it also is found in beds of epidote; it is known in one bed of sandstone and, in rare cases, in felsite. The great sources of copper are the native copper deposits in the amygdaloids and in the conglomerates, but some of the largest masses of native

copper have been found in the veins. One of these is reported to have weighed five hundred tons. The native copper of the conglomerates and amygdaloids is now definitely known to continue downward to depths of at least two miles, and in some cases these deposits are worked along the strike for distances of about five miles. In the conglomerates the copper occurs chiefly in the matrix, but also in part as a replacement of pebbles. Similarly in the amygdaloids the copper occurs largely as a filling of amygdules (commonly with calcite, epidote, chlorite, etc.), and also as a replacement of the igneous rock in the midst of secondary minerals.

The origin of these copper deposits has been a subject of much discussion because of the fact that copper compounds so common in other copper deposits are here very rare. The complete story of the origin of these deposits is not yet known, but there has been a marked tendency in recent years to consider the associated igneous rocks as an important factor in the problem. It may be suggested that the copper was deposited from warm or moderately hot solutions probably containing little if any sulphur.

Chief Deposits. The most important deposits in the district are the Calumet conglomerate and the Kearsarge, Baltic, Pewabic, Osceola, and Isle Royale amygdaloids.

The Calumet lode is the copper bearing portion of one of the conglomerates of the Middle Keweenawan. The bed continues for a distance of several miles, but it has not been found profitable along the strike outside the property of the Calumet and Hecla Mining Company. At greater depth it has been mined by the Tamarack Mining Company. This conglomerate is made up largely of pebbles of felsite and quartz porphyry cemented by small particles of rock, calcite, and native copper, with small amounts of other minerals and occasional pebbles of melaphyres and amygdaloids. Most of the copper is coarse, but a certain portion is in very minute particles so that the ore has to be finely ground to recover all of the metal. The thickness of the lode varies from ten to twenty feet, with unimportant exceptions. The copper tenor of the conglomerate in the upper level averages up to five per cent on large tonnages. For example, in 1888, when the Calumet and Hecla mine was about three thousand feet deep, the ore mined yielded 4½ per cent copper. In 1900 the ore averaged 3 per cent copper. Ten years later it averaged 1½ per cent copper, and in 1918 the average recovery of copper

from the ore mined from the Calumet conglomerate was only 28 pounds per ton of ore. It is worthy of note in this connection that some of the mines in northern Michigan have profitably handled ore yielding an average of only one-half of one per cent of copper recovered per ton of ore. The Calumet and Hecla mine has obtained most of its copper from the Calumet conglomerate and at a cost which has made it one of the leading dividend producing mines of the world. In recent years the company has mined an increasing amount of ore from the Osceola and Kearsarge amygdaloids, both of which are found within its property lines, although the recovery of copper from the Osceola lode averaged less than twelve pounds per ton of ore in 1918, and no copper was obtained from the Kearsarge lode for several years.

The Kearsarge lode is the upper portion of a sheet flow of porphyritic amygdaloidal melaphyre. The amygdules are numerous and large in the lode and are commonly filled with calcite, quartz, red feldspar and green epidote. The copper occurs both in the amygdules and as a replacement of the rock, closely associated with epidote. At Calumet this amygdaloid lies about parallel to the Calumet conglomerate with a dip of about 38 degrees. The copper bearing portion of the lode is being mined, having a continuous stretch of five miles at the Centennial, South Kearsarge, Wolverine, North Kearsarge, Allouez, Ahmeek, Mohawk and Seneca mines. At other isolated points mining is also in progress within this lode.

The Baltic lode is the upper portion of a melaphyre which forms one of the lower parts of the Middle Keweenawan. The rock has a gray or brownish ground mass with amygdules of white calcite. Below this zone is a brown melaphyre with abundant parts of green chlorite. Copper is not confined to the amygdaloids in all places, but extends well into underlying rocks, thus making the lode nearly 100 feet in width in exceptional cases and frequently as much as 50 feet. This lode is faulted in many places, the fissures being filled with white calcite or with soft chloritic material. The Baltic lode is most productive in the region of the Champion, Baltic and Tri-Mountain mines, of the Copper Range Mining Company, where the lode is comparatively firm. Between the Tri-Mountain and Baltic mines there is a marked change in the strike of the lode and probably one or more important faults.

The Pewabic lodes are the copper bearing amygdaloids found in the Quincy mine. In a single lode there are at least four productive horizons in a zone about 300 feet thick. They are approximately parallel and are separated by ordinarily dense melaphyre belonging to a series of dark gray feldspathic lavas known locally as the ash pit series. The copper occurs in the amygdaloidal portion associated with chlorite, calcite, epidote, quartz and prehnite. In this mine also some of the copper is obtained from disseminations in the wall rocks. The lodes are crossed by persistent calcite veins, but these are usually barren and not even associated with the richer portions of the lode, which is about ten feet in thickness.

The Osceola lode is a brown amygdaloid spotted and streaked with white calcite which has been worked by the Osceola, the Calumet and Hecla and the Tamarack mining companies. It is below and parallel to the Calumet conglomerate, having a width of nine to fifty feet. The principal ore bodies in the lode are found near the walls.

The Isle Royale lode is the amygdaloidal upper portion of a flow of diabase having gray ground mass with amygdules containing many minerals, prominent among which are calcite, quartz, epidote, chlorite, prehnite and laumontite. The underlying foot wall is a gray olivine diabase. The lode is worked in the Isle Royale mine south of Portage Lake. Its extension is probably to be found at the Arcadian mine.

Many other lodes have been mined in various parts of the district. Some of them are worthy of mention as scarcely inferior in importance to some of those already named. These include the Lake lode, the lodes of the Mass mine, the Winona lode, the Algomah lode, the Hancock lodes. Copper is also obtained from veins at the Minnesota mine.

In the Michigan copper district the names applied to the coppear bearing rocks and concentrates are quite unusual. Thus large masses of the native metal are called "mass copper" or simply "mass." Smaller masses streaked with rock material are called "barrel work." Rock containing copper in comparatively small particles in sufficient quantity to be minable is known as "copper rock," "stamp rock," or simply "rock." Copper compounds occurring in the mines are called "ore" instead of minerals.

Most of the prospecting in the district is now done by diamond drilling and trenching. A considerable area still remains

to be examined and new discoveries are to be expected, where the outcrops are now hidden beneath a considerable thickness of grayish drift. Exploration is also carried on underground by several mines. This is also done chiefly by diamond drilling. Also in some cases cross cuts are used. Most of the mines are opened by means of inclined shafts, following the dip of the lode, but a few vertical shafts are also in use. After mining and hoisting the ore, workmen sort out the mass copper and rock and feed the remainder to crushers. The ore is held in bins which in some cases are built of concrete and steel and have a capacity up to 2,000 tons. From the bins the ore is drawn off through a chute into railway cars and taken to the mill.

The mills of northern Michigan are remarkable for their capacity. There are fewer than 100 stamps in the district and the tonnage passing under the stamps daily is perhaps greater than in any other copper district in America. The recovery averages about 80 per cent. The stamps are operated by steam and a single stamp may crush from 320 to 700 tons per day. It is not advisable to crush the ore very fine, since some of the copper is in coarse pieces and fine crushing is done more effectively with conical pebble mills after the coarse copper has been saved. After separation of the copper from the stamped ore, the material passes through a screen to jigs and tables. The copper concentrates from these machines, together with the coarser copper, go to the smelters, where the operations are chiefly melting the concentrates and masses in reverberatory furnaces, refining the copper thus separated, and finally recovering as much as possible of the copper which in the first process goes into the slag.

Mining. During the early stages of development, the work was prosecuted in a very elementary manner; hand drills were used with black powder for blasting, and wheelbarrows were the only means of transport. Hoisting was done by the crude hand windlass.

In 1864 John Mabbs made some revolutionary changes at Isle Royale. He built the first hoist with large diameter drum, installed the first air compressor and air rock drills, and made use of the first dynamite employed in this district. From this time until the present developments and improvements have been constant.

Three classes of deposits have been worked, veins, conglomerates and amygdaloids. The vein workings are mainly confined to Keweenaw County and are seldom over 3,000 feet in

Isle Royale Mine No. 4 Shaft and Surface Plant.

Ahmeek Mine Nos. 3 and 4 Surface Plant.

depth. Vein working was the earliest form of mining, generally along a junction with an amygdaloid lode. The amygdaloid lode was first attacked by the Quincy Company, but with little success until the Pewabic Lode was developed.

Shafts and Developments. The general arrangement of shaft sinking and development is important. Owing to great depths which are common and the vertical boundary system of ownership, which obtains in Michigan,* there are two distinct schemes followed in opening up the mines.

Where the mining companies' holdings include the outcrop of the lode, the shafts are usually sunk in the lode and follow the dip of the ore body closely. In several cases this dip shows a tendency to flatten out with depth, and the inclination of the shaft is gradually lessened to correspond to this tendency.

Such properties as those of the Tamarack Mining Company, Allouez Mining Company, Ahmeek Mining Company and Seneca Copper Company are so situated that the holdings are far down on the dip of the lode. Vertical shafts and shafts which are sunk vertically to the lode, and then are flattened to follow its dip are used under these conditions.

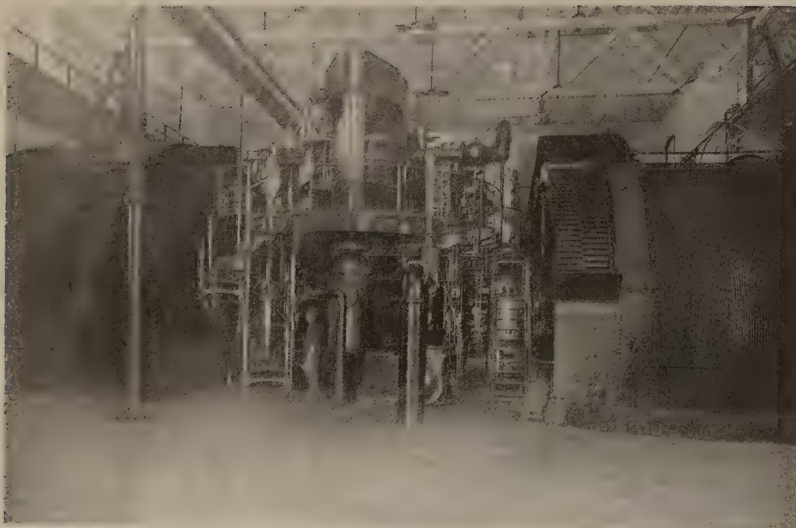
In the vertical shafts Kimberly skips are used to handle the ore. In the inclines, four wheeled skips of from 3- to 10-ton capacity are used. These are interchangeable with special man cages for handling the crew in and out of the mines. Cages for hoisting have been used only in the Tamarack shafts.

Hoisting Equipment. The hoisting equipment is of various designs. Red Jacket uses a drumless hoist. The Whiting system of hoisting with tail rope is used. Number 5 Tamarack uses two Nordberg hoists, the drums of which are mounted at the apex of an A Frame—upon the sides of which are mounted the four cylinders. These are mounted at an angle of 45 degrees from the horizontal. The drums are cylindrical; the hoist is designed to raise a loaded cage from a depth of 5,300 feet in three minutes.

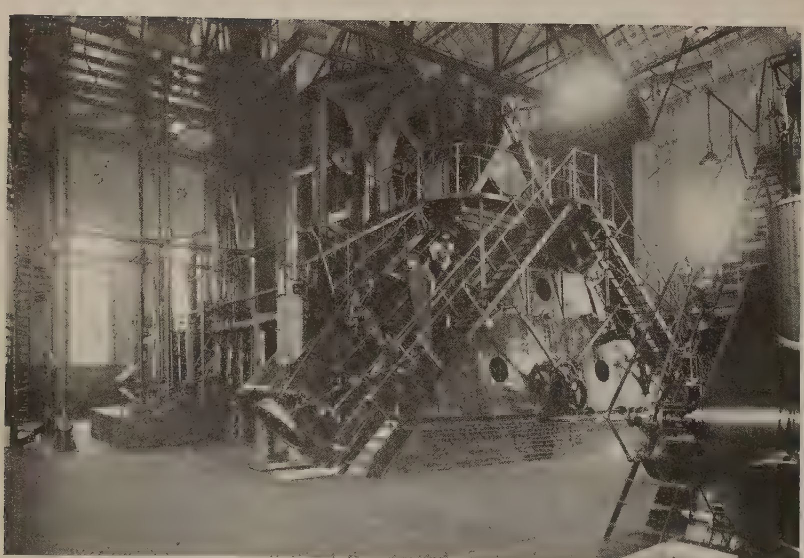
At Champion "E" shaft a Nordberg first motion horizontal Duplex Corliss hoisting engine, with a cylindro-conical drum is used.

Several other makes and types are in use in the field, the general tendency being one of high speed hoisting due to depth. Signaling systems are various in design. Rope and bell signals are used, as are electric systems. Telephones are installed at all

*By act of Congress, Michigan and Minnesota are excepted from the provisions of the Apex law, which is the source of so much litigation in western states.



Houghton and Seneca Engines, Calumet and Hecla Company.



Main Hoist No. 5 Tamarack Mine, Calumet and Hecla Co.

underground stations, the phones being connected to the main switchboard of the particular company they serve. Rapid and direct communication between the various departments is thus assured.

Air Compressors. The most notable compressors built are perhaps numbered among those used in the Lake Superior copper district.

At the Victoria mine a hydraulic compressor which traps the air, compresses it to 117 pounds per square inch gauge pressure, and delivers it to an eighty thousand cubic feet chamber underground has been installed and is in operation.

At Calumet, the Calumet and Hecla has a compressor, consisting of three sets of high pressure and three sets of low pressure cylinders, with a capacity of 27,000 cubic feet of free air per minute compressed to 65 pounds per square inch.

There are numerous compressors with capacities of from 4,000 to 8,800 cubic feet of free air per minute at the various mines. The pressure range varies from 65 to 100 pounds per square inch.

Electric Power. Calumet and Hecla has its own central station at Torch Lake. Here power is generated by steam turbine driven alternators for mines, mills and smelters. This plant is complete in every sense, with modern appliances. Several of the smaller companies maintain similar installations.

Mining Methods. The mining methods in the Lake Superior copper district have undergone many changes. One factor in the amygdaloid mines has been the extraction of the mass-copper. This was originally cut by hand chisels, but of late years this work is all done by pneumatic chisels. Some of the masses require a great amount of work of this nature.

Overhead stoping is the general method used in the district. In the early work in the conglomerates, a system of square setting with the posts set normally to the dip was employed. This system was not satisfactory as the amount of timber used was excessive and the load was not well carried by the system. The labor of erection was excessive and irregularities in the thickness were not well met by the square sets.

The square setting system has been entirely replaced by the so-called battery timbering system. This system of timbering is more flexible, and is more easily applied. In this system posts are set in pairs. Each pair is eight feet from the next measured along the strike of the vein. In reality they are simply a pair

Mass copper on 12th level north No. 2 shaft, Ahmeek Mine.

of stulls set together. A third post is placed later. These third posts support the caps which are continuous along the vein, and with the caps form a modification of a continuous drift set. They are so placed that they are adjacent to the other two. The spacing along the dip may be varied as made necessary by local conditions. This was an impossibility with the square sets. The assembly is spragged to the one just below to prevent movement down the hanging wall.

Mining on any level starts midway between shafts which are spaced from 800 to 3,000 feet apart. Main levels are driven 100 feet apart on the dip. Mining is started on each side of shaft and is carried back toward the shaft, safety being much greater, and the tonnage more readily regulated by this method. Level pillars are extracted as part of the regular mining operation.

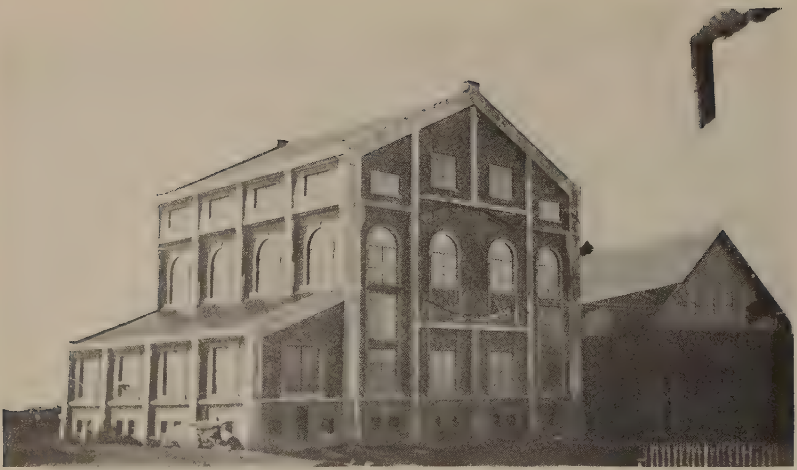
In the amygdaloids the same general conditions exist. No timbering is done. Where the hanging wall is good, the only support is a series of chain pillars just above the main head, with narrow dead-end pillars running from level to level about every 300 feet; or a series of staggered circular pillars is left in place of the chain pillar above mentioned.

In general the broken ore is led by chutes directly to the mine cars, no great amount of shoveling being necessary. In these operations the stopes are left open, no filling being done. In the case of the Copper Range Co., the pillars mentioned are omitted and a dry wall with chutes replaces the chain pillar.

Where the stopes are filled, the filling is carried upward as fast as is necessary. Originally ore-filled stopes were tried out. Later waste filling was adopted and has been since considered a standard method.

In the early development of the waste filling system, the filling was held by drift sets and the chutes were in the form of cribbed raises. The enormous cost of installation and upkeep, and the delay in operations at the shafts due to handling so much timber brought about a change and a system known as the "dry wall" method was adopted.

This system briefly is as follows: The main level drift is driven. A cutting out stope is started and the waste rock is left in the mine. This stope extends the full width of the lode at the outset. A parallel pair of dry walls, laid up entirely from the waste is started along the lines of the sides of the drift. Except for those distances which must be served by double track in which the width of the completed drift is nine feet, the drift width



Hoist house No. 2 Shaft, Quincy Mining Co., Hancock, Mich. The building is 76x95 feet and is constructed entirely of reinforced concrete. The walls are brick veneer and the concrete roof is covered with green tile. All the windows are glazed with horizontal ribbed glass and are mechanically operated for ventilating purposes.

Clubhouse Building, Quincy Mining Co., Hancock, Mich. Building is 30x90 feet and constructed of brick. The first floor is used for baths and on the second floor is located the library, reading room and auditorium.

is uniformly seven feet. The walls are seven feet high. They are four and one-half feet thick at the bottom and four feet thick at the top. The tendency of the rock to break into flat slabs materially aids in the construction of rigid walls. When the walls are laid up to a height of seven feet, a 2x12 plank is laid along each wall close to the drift side. This serves to distribute the weight transmitted by the caps over the entire length of the wall, and prevents cutting into the wall by caps at the point of contact.

Next the caps are laid. They are large hardwood logs, fourteen feet long for the seven feet drifts, and are placed to be equally divided each side of the center line. The spacing of the caps is regularly three and a half feet centers.

At points 70 feet apart along the drift provision is made for chutes. Timbers are laid in walls above and below chute openings to which chute lips may be fastened. Chutes are built up of double dry walls, an inner and an outer wall being provided, the space being filled with small rock. The chutes rest upon timbers placed in the main walls. The chutes are carried upward as rapidly as needed.

The stopes are carried the full width of the lode and irregularities are easily followed. All broken rock is sorted and only that containing copper is hoisted. The waste is thrown back of the walls and filling begins. When the stope is filled above the lagging on the caps, the chutes are carried upward. All rock blasted is sorted, and all waste is left in the stopes. When this is insufficient, the hanging wall is drifted into and additional waste secured.

By this system, a large load is taken from the hoisting apparatus, as comparatively little timber is needed. All the waste remains in the mine instead of being hoisted. All stoping is done on the waste floor, which is close enough to the back to make conditions safe. Irregularities are no drawback, as the system possesses great flexibility.

When the work has been carried up close to the level above, the level pillar is caved. This is the last step in the system. As the load comes it brings in the material from the stope above. The extraction by this system is almost complete.

The largest operating company in the district is the Calumet and Hecla Mining Company. Copper Range Consolidated, Ahmeek, Quincy, Osceola and others have all played an impor-

tant part in the development of the district. Being the principal taxpayers, the maintenance of the school systems has largely devolved on the mining companies. Hospitals, clubs, ambulance service and other improvements are maintained by mining companies.

RECENT DEVELOPMENTS IN COPPER MINING PRACTICE IN THE LAKE SUPERIOR DISTRICT.

By Ocha Potter.

The outstanding feature of the situation in the Michigan copper district is the fact that the market price of copper is insufficient to more than barely meet operating costs, leaving nothing with which to meet depletion, depreciation, etc., or to attempt a much needed program of mining development, exploration of new territory and improvement in mechanical equipment.

The average price of copper for the ten years preceding our entrance into the European war was approximately 16⅔ cents per pound, and the present price is about 18¼ cents per pound, an increase of approximately 10 per cent. As compared with the ten year period just mentioned, wage rates and the price of supplies have practically doubled, and this has resulted in a situation which is taxing the very best engineering and managerial ability in the industry. The result has been that some of the lower grade or less fortunately situated mines have suspended operations entirely, and most of the others have adopted a policy of curtailment until the enormous surplus of copper left in the hands of the producers after the signing of the armistice has been absorbed.

There is little doubt that if the copper companies were to proceed upon the basis of self-interest only, practically all of our mines would close down until the situation had adjusted itself. However, Houghton and Keweenaw counties, with their combined population of 110,000, are almost wholly dependent, either directly or indirectly, on the business of copper mining, and the various managements feel that only absolute necessity would justify the hardship and disorganization that would follow a complete suspension of operations.

Fortunately, some of the larger companies began in 1911 and 1912 an extensive campaign for the improvement of mining and metallurgical methods, and it is almost a certainty that if it

were not for the results of this campaign, there would be but two mines in the district that would be able to meet operating expenses under present conditions. A description of the improvements that have taken place in milling and metallurgical practice I leave to some one more familiar with the subject, but to those of you who may be interested, I would suggest Mr. C. H. Benedict's article in the Engineering and Mining Journal of July 5th, 1919.

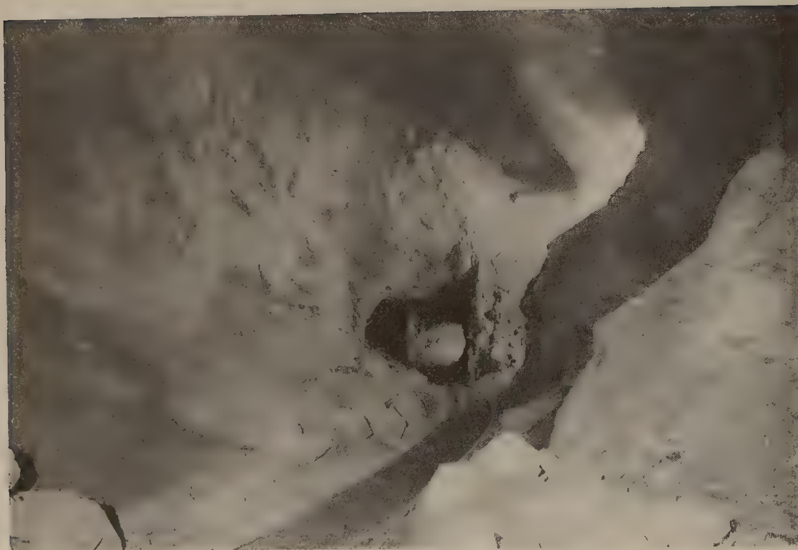
What is probably the lowest cost copper now being produced anywhere in the world is that being reclaimed from the former waste tailings of the Calumet and Hecla conglomerate mine. The dredge used in recovering these tailings is one of the largest in existence, having a maximum capacity of 10,000 tons daily, and digging to a depth of 100 feet below the surface of the water. The suction ladder is 155 feet long and both suction and discharge are 20 inches in diameter.

Unfortunately, treatment of the amygdaloid ores has not kept pace with that of the conglomerate ores. Owing to the low grade of most of the amygdaloid ore, the tailings are so lean in copper content that leaching, flotation and extreme fine grinding have no economic application. Improvements in the mills of the amygdaloid mines have, therefore, been almost wholly confined to a modified fine grinding and to the saving of coal by the introduction of low pressure turbines for utilizing the exhaust steam from the stamps. In general, therefore, milling costs per ton of amygdaloid ore have increased in direct ratio with the increase in wage rates and supply costs, and as approximately two-thirds to three-quarters of the copper from the district is produced from the amygdaloid mines, it will be appreciated that the hope for the future lies in some other direction than in the lowering of milling costs or the increasing of milling efficiency.

To the average mine executive, it is hardly necessary to say that transportation costs have doubled or more than doubled, with no prospect of immediate future relief.

The copper country has, for many years, been noted for the efficiency of its hoisting and coarse crushing equipment, and here again costs have increased directly in proportion with the rise in wages and the price of supplies.

A careful analysis of the situation, therefore, leads to the inevitable conclusion that, leaving aside the question of the selling price of copper, our best chances for remaining a factor in



Osceola Lode, 21st Level South, No. 2 Shaft, Tamarack Mine.

the business of producing copper, lie in the possibility of the improvement of underground methods, and it is largely the object of this paper to indicate something of what has been accomplished and what is being attempted in our underground departments.

By far the greatest improvement during the last ten years was the development of the so-called one-man drilling machine. To most of you, it is probably familiar history that the co-operation of the Calumet and Hecla underground organization and the Ingersoll Rand Company in 1911 and 1912 resulted in the almost complete abandonment of the use of reciprocating drills and solid drill steel, and the substitution therefor of the various types of the so-called hammer drills and hollow drill steel that has followed. It is an interesting fact that if the efficiency of the drilling machine runners had been as low in 1918 as it was in 1912 with the old type piston drill, we would have required approximately 3,000 more miners in this district alone in order to give us the production which we finally attained. The stope miners of the Calumet and Hecla mines produced 11.42 tons per man per shift in 1912, at a cost of 35 cents per ton for supplies and labor. In 1919, this same class of labor produced 26.29 tons per man per shift, at a cost of 34 cents per ton, with an increase in wages and supplies of over 100 per cent. This development meant the release of some 3,000 men for war work, either as soldiers in the service or as workmen producing war materials.

No discussion of the development of the water hammer type of drill and the use of hollow drill steel is complete without paying deference to the genius of J. George Leyner, who we understand invented the former, and to the enterprise of the steel companies who developed the present process of making hollow drill steel. Limitation of space will not permit me to go into as much detail as I would like in the discussion of drilling machine practice, but the following is a brief summary of copper country methods:

Drilling Practice.

(1) Drilling machines are of the mounted hammer type, using water, and weighing from 125 to 150 pounds; drilling approximately horizontal holes in stoping.

(2) Hollow hexagon drill steel of ⅞ and 1 inch diameter is almost universally used, the former size being common in the softer amygdaloid lodes.

(3) Lugless steel is used in all the mines with one exception, drilling machines being of the anvil block type.

(4) Bits are of the Carr type, either single or double; starting gauge from 1⅝ to 1¾ inches and decreased by 1/16 inch to each 44 inches of run in the softer amygdaloid, and 1/16 inch to each 12-inch run in the Calumet and Hecla conglomerate.

Former starting gauges were about 2¼ to 2½ inches with piston drills, with a usual reduction of about ⅛-inch to 12 inches of run.

Drilling speed varies inversely as the volume of rock cut, that is, as the square of the diameter of the hole drilled, so that the advantage of a type of bit which will permit drilling as small a hole as possible is very obvious.

Cutting angles are usually 105 degrees and the clearance angle is 9 degrees in the amygdaloid mines of the Calumet and Hecla group and 14 degrees in the conglomerate.

(5) Maximum length of drill steel varies from 10 feet in the conglomerate to 16 feet in the amygdaloid.

(6) Air pressure varies from 70 pounds at some of the mines to 100 pounds at the Quincy and Seneca. The tendency is toward higher air pressure, and the Isle Royale mine has recently made changes in its compressors so that pressure at the present time is approximately 90 pounds. The Calumet and Hecla is experimenting along this line on its conglomerate lode by means of an electric booster, which gives us a possible pressure of 100

pounds for a very limited number of machines. In general, it appears that the drilling speed increases about 1¼ per cent for every increase in air pressure of one pound above 70 pounds.

(7) Most of the mines pipe water for drilling purposes directly to the machines, the half-inch to three-quarters inch water lines being laid with the air pipes. Water boxes with automatically controlled valves are stationed at various points in the shaft and gravity supplies the necessary pressure to force the water to the machines.

(8) Ammonia explosives are used almost entirely, and for stoping purposes 40 per cent to 45 per cent is most common. Sizes are one inch or one and one-eighth inch. Some of the mines make a practice of using 60 per cent powder for drifting and shaft sinking.

Tramming.

The Quincy and Copper Range mines have for many years used trolley locomotives for haulage, but this was due in large part to the fact that the character of their deposit was such as to permit a considerable concentration on certain levels.

It was only until the past two or three years that, due partly to the successful development of small unit battery locomotives, partly to the greatly increased concentrated tonnage possible because of the new type of drilling machine, and partly to the growing scarcity of tramming labor, the Calumet and Hecla group of mines have seriously considered the question of underground locomotive haulage. The use of rope haulage has been universal in the conglomerate lode for many years and is still standard practice.

At most of the amygdaloid mines, however, we have adopted four-ton single motor battery Goodman locomotives, but their use is confined to levels where production is at a maximum. In general, each locomotive has its own 25-horsepower charging set. The batteries are of three types—the Edison, the Ironclad Exide and the Philadelphia Pasted Plate.

A complete description of storage battery locomotive practice would in itself consume more space than is available for this paper, but in general, results have been all and more than expected. We now have 48 of them and for runs up to 2,000 feet the battery locomotive has a field all its own, under our mining conditions. The ability to go wherever a tram car can go without waiting for trolley wires or bonding of rails, makes it invaluable under present labor conditions. Over an average distance

of 800 feet we find that we can haul about 6.8 tons for each kw. hr. and this includes lighting at the stations.

Coincident with the introduction of locomotive haulage was the development of better tram cars and better arrangements for dumping into the skips. It was considered desirable to avoid the use of storage chutes and loading pockets, as every additional operation means increased cost. To permit of a maximum production from a given shaft it was, of course, necessary to reduce skip loading time to a minimum, and therefore, as far as practicable, large cars have been adopted, and these are dumped directly into the skip by means of air lifts. Where 5 ton skips are used, we have adopted 5 ton tram cars on motor levels, and where we have 7½ ton skips, it is common practice to use two 3½ ton cars which are dumped into the skip simultaneously. Motor boys now dump both types of car without help in from twenty to thirty seconds, whereas, with the hand dump cars it requires two men and takes an average of about 1¼ minutes to dump two 2½ ton cars.

Five trolley locomotives are in use at the Allouez mine, and this installation differs little from the others in the district, except that 120 volt current is used instead of the customary 225 to 250 volts. The generator is located underground, however, instead of being on surface.

Loading Methods.

The use of chute loading from stopes has become very general with the adoption of larger cars. At some of the mines, chutes 4 feet by 4 feet by 8 feet, with 25 foot centers, are blasted through the solid vein. As the stopes advance along the level, the tops of these chutes are opened and the stope ore loaded through them directly into the cars. When the level below is worked out, the floor pillar and chute pillars are blasted down to the lower level so that only the drift dirt—approximately 10 per cent of the total—is shoveled by hand. This so-called pigeon-hole method has resulted very satisfactorily, especially where the vein is steep enough for the broken ore to run freely, and also where the hanging is broken and shows a tendency to cave.

Taking the district as a whole, probably 60 per cent of all ore hoisted at the present time is loaded by means of some type of chute or high sollar.

The development of some form of machine loader has been receiving very serious consideration and at least four companies in the district have plans under way for building a machine of

their own design. Several of the loaders now in the market have been tried out with little success, owing to the fact that the limited tonnage available at any one level makes a large expensive machine impracticable, while the coarseness of the broken ore is such that the smaller types cannot handle it.

Slushers of various designs are being given an extensive trial and they appear to be very successful in high, flat stopes, where the broken ore will not run freely to the level. It is possible that the field for slushers may be considerably widened as a result of experiments now being made.

Concrete.

A few years ago, the use of concrete for shaft and plat supports and for shaft stringers became very popular. Time has exposed the fallacy of using concrete for this work under our conditions, and it is no exaggeration to say that the experiment has cost the copper country mines hundreds of thousands of dollars. As is perhaps well known, there is frequent slight movement in the rock surrounding our shafts, and no concrete yet devised will withstand this movement, with the result that once cracked, even slightly, the concrete becomes a menace and must be removed, often at considerable expense, both in money and in time.

As a result, the mines have gone back to timber for skip roads and shaft and plat timbering.

Loading car from chute Calumet Hecla Conglomerate Mine.

Selection of Ore in Stopes.

In 1918, the Calumet and Hecla group of mines recovered an average of 17.76 pounds of copper per ton of ore stamped. Rising costs and decreasing prices for copper made it advisable to raise the grade and this has been accomplished, not by selecting especially rich areas for stoping, but by giving very close supervision to the drilling of the individual holes in the ordinary process of stoping. At some of our mines this was accomplished by hiring so-called "stope bosses," whose sole duty it is to see that the drilling of holes in poor or very lean ground is eliminated as much as possible. While this policy has, of course, resulted in a somewhat higher cost per ton for stope miners' labor and supplies, it is evident that the cost per ton for tramming, freight, stamping and all other operations remained approximately constant.

This policy has been so successful that in 1919 the average recovery from the same mines was raised to 20.54 pounds per ton, and for the first five months of 1920, it has averaged 22.34 pounds, or better than 25 per cent over the recovery of 1918.

The success of this policy has opened a very promising field for cost reduction, and it is probable that considerably better results may be obtained by an even more rigid application of this method.

Filling of Mines.

At the Copper Range mines, the practice of filling empty stopes with waste sand has been abandoned, due to the fine grinding methods introduced in the past few years, which makes the tailings so fine that it is impracticable to handle them by the usual method of blowing through pipes with compressed air. Sufficient waste rock is now selected from the broken ground to fill the old stopes and this has a double advantage in the fact that the higher grade ore resulting from closer selection permits of better metallurgical treatment and a higher mill recovery.

The Quincy mine has adopted a so-called poor rock pack system whereby a fill of poor rock of about 20 feet is left both above and below the worked-out level. This has resulted in practically complete relief from air blasts in the areas that have been treated in this way. The stopes in all the other mines in the district are left open and the hanging permitted to cave.

Beginning of stope and general construction of dry wall drifts.
Copper Range Mines.

Dry wall drift, dry wall method.
Copper Range Mines.

System of Wage Payment.

As is probably well known, the Lake Superior copper district was a pioneer in adopting the contract method of payment for its underground men, and today practically all mining and tramming is done either on a contract or bonus system.

The old Cornish fathom basis for stoping contracts has been abandoned in favor of the ton. For drifting, the foot of drift is, of course, the unit, and for tramming, the pay is usually based on the number of cars filled.

The ideal contract is one in which only one man is involved and, in general, an attempt is made to limit each individual contract to as few employes as possible.

Contract prices and bonus requirements have been the subject of very careful study with the object in view of fixing rates that would be relatively permanent. Nothing has been more prolific of ill feeling and dissatisfaction in the past than the monthly adjustment of contract prices. Today the contractor is assured that if he makes a very high wage due to special effort on his part, he not only will get all he has coming to him, but his rate will remain the same, and, in addition, he will receive every encouragement on the part of his superiors to do still better.

General.

The Quincy Mining company has nearly completed the erection of a Nordberg triple expansion steam hoist, which it is expected will be capable of hoisting in one stage from a depth of approximately 13,000 feet. The size of the drum—30 feet by 30 feet—gives only an inkling as to the size of this machine.

The Copper Range mines have devised a regenerating system for heating company buildings. Waste steam from their hoists is used. The amount of coal used for heating purposes is seldom appreciated, and under present conditions in the coal industry, any attempt at coal saving is a move in the right direction. The Range mines have also introduced the use of an indicating pyrometer for tempering drill steel which has met with great success.

It is expected that papers on both the regenerating system and the heat treatment of drill steel will be read at the August meeting of the A. I. M. and M. E.

One of the greatest causes of annoyance, lost time and general inefficiency of drilling operations is the necessity of frequent changing of drill steel. It would seem that the time is nearly ripe

for the bringing forth of something in the line of a new alloy steel that will withstand abrasion several hundred per cent better than the steel now on the market. Our companies could well afford to pay double the price of the present steel if, by doing so, they could obtain a bit that would stand double the wear.

The Seneca Copper Company has sunk a 9 foot by 21 foot shaft which is vertical for 1,320 feet, and then curves through 608 feet on a radius of 600 feet, and finally goes down parallel to the lode on a 34 degree dip. This is the only shaft of its kind in the district, and its operation will be watched with great interest.

A very ambitious attempt at shaft raising is that recently undertaken by the Calumet and Hecla in connection with its proposed 81st haulage level. This shaft is being raised full size—9x20—from the 78th level to the 57th level (nearly 2,100 feet) without any intermediate connection. The shaft has now reached about 900 feet in height and is progressing at the rate of approximately 125 feet per month. Permanent track, timbering and piping is being installed so that when finally holed, the shaft will be ready for operation. The angle of dip is 34 degrees from the horizon.

Conclusion.

It is an interesting observation that the very fact that conditions in the copper industry are, to say the least, unsatisfactory, has led to a closer co-operation among the engineers and executives and perhaps, after all, in the end it may prove somewhat of a blessing in disguise. There are enormous tonnages of low grade copper rock just as there are of low grade iron ore, which may some day be made available through an application of some of the methods now being evolved by the pressure of stern necessity.

The young engineer looks forward with eager ambition and great confidence in his ability to do things that have never been done before.

The older engineers and mine executives say that times have been worse than this in the industry. Look at '93. And we have had at least three real booms since then.

Perhaps, after all, they are both right.

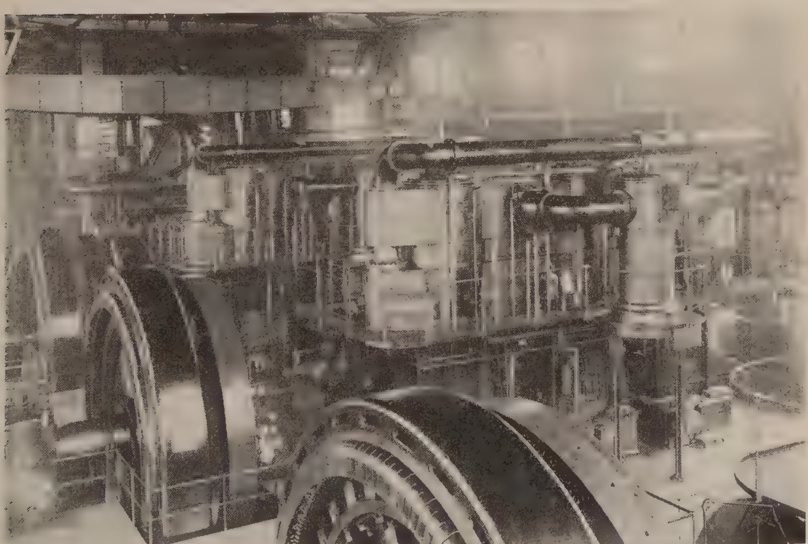
DEVELOPMENTS IN LAKE SUPERIOR MILLING*

As is well known, two principal types of copper ore are mined in the Lake Superior region, both of which contain native copper, but which differ materially, not only in the physical character of the gangue, but also in the physical character of contained copper. The conglomeratic ore is a hard, close-grained rhyolite, characteristically composed of pebbles, in which the copper forms the cementing material in the interstices between the pebbles. In the amygdaloidal ore, on the other hand, the copper occurs in more massive form than in the conglomerate and the rock is much softer.

Numerous amygdaloidal lodes are being worked, and each lode differs to some extent from all the others, both in physical characteristics and in rock constituents, and more particularly as regards the richness of the ore and the size and distribution of the copper particles. The only conglomerate ore mined at present is from the Calumet and Hecla mine, and, inasmuch as the lode is rich and the copper is in a fine state of subdivision, metallurgical development has been more pronounced in the treatment of this "rock" than in the case of any other "rock" in the district.

The question of the best metallurgical treatment of the amygdaloidal ore is most often a compromise between the pos-

*Abstract of article by C. H. Benedict: Eng. Min. Jour., vol. 108, 1919.



Power House Calumet Hecla Stamp Mills.

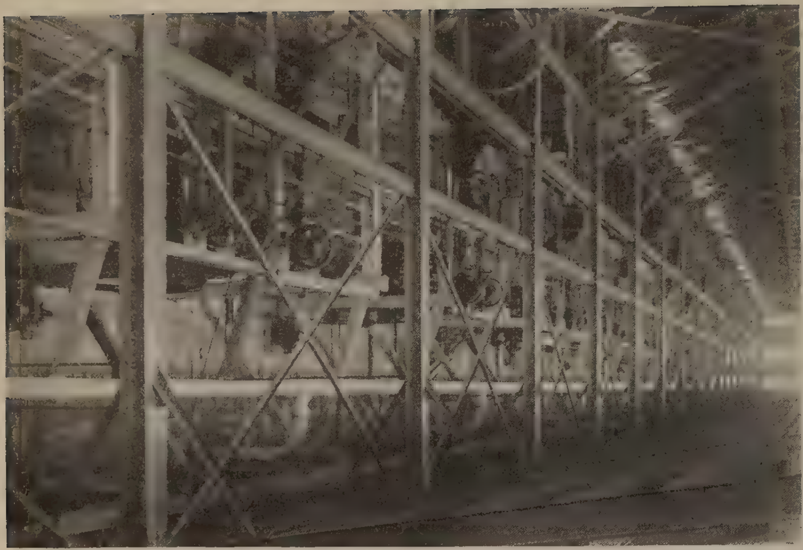
No. 1 Stamp Mill, Quincy Mining Company, Mason, Mich. The stamp mills of the Quincy Mining Co. contain eight units (five of which are in No. 1 mill) each unit having a capacity of 700 tons per 24 hours. Primary crushing is done by a steam stamp at each unit. The product of each stamp is treated on 28 jigs and 9 Diester Plat'O tables. The jig tailings for each unit are reground in either a Hardinge or Marcy ball mill and this product is treated on 30 Diester Plat'O tables.

General view of Isle Royale Mill.

sible metallurgical recovery and the economics of that recovery. That is to say, though it is possible to get a high metallurgical recovery, because of the nature of the ore and the general simplicity of the metallurgical treatment, it is not always economical to carry that recovery to its highest point, as the additional value is not warranted by the increased cost incurred. The richest ore now milled in the Lake Superior region comes from the Champion mine of the Copper Range Co., which throughout 1918 gave a recovery of 36.6 lb. copper per ton of ore milled, with a tailing loss of probably six to seven pounds per ton. The lowest-grade ore profitably milled in the district during the same year was from the Kearsarge lode of the Osceola Consolidated Mining Co., which yielded only 12.62 lb. per ton, with a tailing loss of less than four pounds.

It is obvious that it is possible to carry the metallurgical treatment of ore further when one is treating material assaying 40 lb. copper per ton than would be possible with corresponding material assaying but 16 lb. copper per ton. If one is inclined to criticize the lack of fine grinding or some other relatively crude method prevailing in some mills, one must take into account the fact that the fine copper may not be present in sufficient amount to warrant a better process. The amygdaloidal ore mined by the

Ahmeek Stamp Mill. Location, Hubbell, Mich. Equipment, eight steam stamps with necessary concentrating machinery. Capacity, 5,000 tons per day.



Calumet and Hecla Stamp Mill. View shows stamps in Hecla Mill. There are 17 of these units in this mill and 11 in the Calumet mill adjoining it. Each of these units has a capacity of 350 tons per 24 hours on conglomerate rock and 500 tons per 24 hours on amygdaloid rock.

Calumet and Hecla Stamp Mill. Concentrating machinery. View shows mineral loading tracks with Wilfley tables on either side.

Isle Royale Mining Co., for example, contains a large percentage of heavy copper, so that it is possible to make a recovery of more than 80 per cent by stamping it in a steam stamp and screening it to a maximum size of $\frac{3}{16}$ in. without the necessity of finer grinding of the $\frac{3}{16}$-in. material. On the amygdaloidal ore of the Kearsarge lode, and also on that of the Pewabic lode, the metallurgical recovery is not nearly as good for the same degree of crushing. To get satisfactory results it is necessary to resort to regrinding of the coarser tailings.

In all of the amygdaloidal lodes the copper is in a coarser state of subdivision than in the Calumet conglomerate. Thus, to release the mineral values, it is necessary in the case of the Calumet conglomerate to grind to a finer size than for the amygdaloidal ore.

One feature that must be clearly understood in any review of the metallurgy of Lake Superior is the influence of the presence of coarse metallic copper, because of the fact that it is metallic and therefore not subject to subdivision at the will of the operator. As is well known, one may have masses of metallic copper underground of almost any size up to hundreds of tons' weight, but as the ore comes to the mill the largest masses of copper have been cut up and one must reckon with pieces that might be contained in rock of the maximum size of, say, 12 by 12 by 14 in. dimensions. It is because of the possible presence of

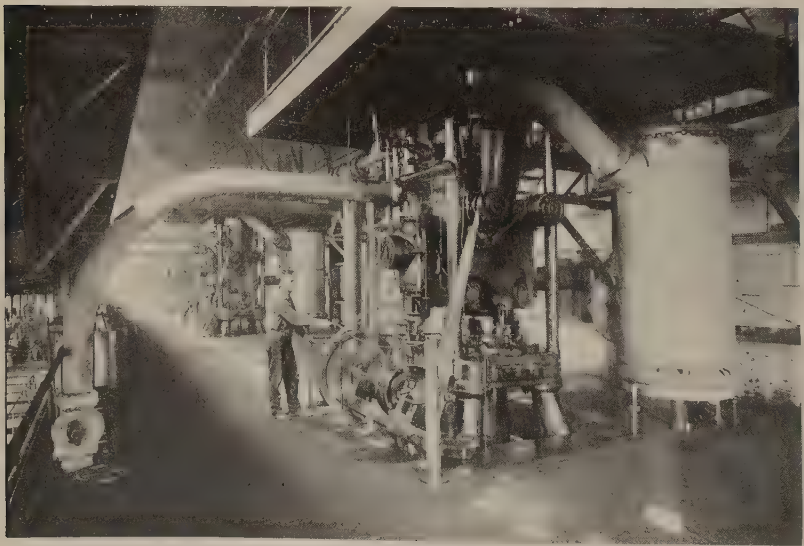
No. 1 Regrinding Plant. C. & H. Mill. Contains 24 conical mills 8 feet in diameter by 72 inches cylindrical length. Receives its material from the tailings of the jigs of the stamp mills.

masses of copper of this size that the automatic feeding of stamps has not been practiced in the Lake Superior region.

It would be easy to devise a feeder for a stamp that would maintain the proper load in the mortar, and many efforts have been made in this direction, but until some one can devise a plan whereby the large masses of copper can be automatically removed from the heads at the same time, there will be no saving of labor in having the automatic feeder, because it is essential to have an attendant present at the feed shoot to remove the large masses of copper. If they get into the mortar they may cause serious damage, such as the breaking of the shoe, stamp stem or piston rod, and if they do not do this, they will accumulate in the mortar to such an extent as to make necessary the removal of the grates and the shoveling out of the mortar contents. This refers to masses of copper eight or ten inches in size.

Provision has been made for the removal from the mortar of masses up to three or four inches in size by means of two devices patented about 1900. The devices are known as mortar discharges and have for their object the removal of coarse copper from the mortar, for which purpose they are most effective.

One device is a plain hydraulic discharge opening into the mortar through the staves at a point about five inches below



Stamp Mill. Runners floor showing steam cylinders in stamp mill.
L. M. S. & R. Company.

the level of the bottom of the mortar grate. The other device also operates through the staves, but at the level of the bottom of the mortar grate, and is in the nature of a jig with a pulsating current, as opposed to the constant hydraulic pressure used in the Krause discharge. These two devices are effective in removing from the mortar such copper as may be within their range, which is roughly from ⅝ up to 4 in. in size, and any copper coarser than this should be removed by the stamp attendant, or "head feeder," as he is locally known. It is the presence of these large masses of copper that makes it impracticable to use a gyratory crusher or even coarse rolls for the preliminary crusher, and the steam stamp has been unique and unchallenged for this purpose.

It is not only on account of the size of the copper that the steam stamp is so efficient, but also, strange to say, because of the shape of the copper. This is really worth consideration, as those who operate mills in the Lake Superior region find a great deal of confusion of ideas on the part of the sulphide-ore operators in respect to the last-named feature.

Before the days of flotation the most common criticism heard of Lake Superior practice was the opinion that the steam stamp caused too much abrasion and consequent loss of copper. To anyone who has tried to abrade copper, and then at the same time attempted to crush amygdaloidal rock, the fact would quickly be forced home that the rock will slime while the copper still remains in its original form. Further than this, it is really necessary that the copper be somewhat "punished" before it is given jig or table treatment. A great part of the copper is in such shape that the surface is out of all proportion to the mass, and by the action of the stamp it is either hammered into a more compact body or is subdivided into a number of pieces each more compact than the original. This matter of the shape of the copper particles becomes much more important in the finer states of subdivision, where forces other than gravity have freer play.

In the early days the inefficiency of the metallurgical process was recognized just as keenly as it is at present, but there was no form of fine grinder that was sufficiently cheap in operation to warrant its installation on these relatively low-grade ores; more particularly so because, even with the release of the copper particles from the ore, their recovery was problematical.

The use of rolls for fine grinding was not a success and could not have been a success, because they simply cracked the particles

Regrinding Plant, Calumet and Hecla Mill, recovering material from dredge, shown on page 49.

of rock and released the copper in its original shape, which ordinarily is so pronged and irregular that it could not be saved on a vanner or on a Wilfley table. The same general effect is produced with the Huntington mill, the crushing action of which is similar to that of a roll. The effect of the shape of the copper was definitely recognized by the early operators, who attempted to use grinding devices that would put the flat copper particles into more of a pellet form. For this reason the old Herberle grinder found great favor in the Calumet and Hecla mills before the days of the Wilfley table, because its action was such that the copper was rolled up into a globular or pellet form which was easily saved by a jig.

At present a crushing device is being developed which it is confidently believed in some quarters will accomplish the same result. The device is known as the Lovett grinder. It is a horizontal disk grinder, one of the disks having an oscillating and the other a circular motion, so that the grains of rock are torn apart and the copper is rolled up into a more compact form than it originally had in the ore.

It was not, however, until the introduction of the Chilean mill, taken in conjunction with the Wilfley table, that it was pos-

Dredge. This is a suction dredge with 20-inch centrifugal pump equipped to dig 100 feet below the water line and to deliver through 3,000 feet of discharge line. This dredge is used for reclaiming the accumulated sands in Torch Lake. It has a maximum capacity of 10,000 tons daily.

sible in the Lake Superior region to obtain an economical recovery of copper from particles finer than $\frac{3}{16}$ in. The Chilean mill had not met with great favor in Western practice, because of its sliming proclivities, which made it, on the other hand, acceptable to native-copper metallurgy. The copper freed by the Chilean mill was in the shape of flat grains and was in excellent condiion for a good recovery by the Wilfley table. Up to the time of the introduction of the pebble mill, the Chilean mill was the only type of fine grinder used generally in the Lake Superior region, and it found a place in the stamp mills, not only of the Calumet and Hecla Mining Company, but also of the Copper Range, the Mohawk, and the Lake Milling Company.

With the introduction of the Hardinge grinder, which fortunately occurred at about the same time that cheap power became available, owing to the adaptation of the low-pressure turbine to the utilization of the exhaust steam from the stamps, fine grindings may be said to have secured an established place in the metallurgy of the Lake Superior district. Each important plant now has one or more mills in operation, and each operator has attempted to find the economical point to which this fine grind-

Steel Shaft Rock House at No. 2 Shaft. Quincy Mining Company, Hancock, Michigan. This structure is of concrete and steel, 44 feet by 150 feet and 160 feet high. The building contains one Blake crusher, 18x24, for crushing "poor rock," and two 24x36 Farrel crushers, which crush the "copper rock" from 20 inches to 3 inches, at a cost of about 4 cents per ton. This crushed ore then falls into a circular bin 44 feet in diameter, having a capacity of 2,000 tons, from which it is loaded, through air operated aprons, into railroad cars for shipment to the stamp mill.

ing can be carried on his particular ore under the varying conditions of the copper market.

In the Isle Royale plant, which has a capacity of about 2,000 tons of ore per 24 hours, one mill is in operation, regrinding middlings from the jigs and tables; and this seems to be about the proper practice for the ore, as it contains a large percentage of the copper in coarse particles. In most of the mills treating amygdaloidal ore, however, the practice is to have at least one pebble mill for each stamp unit of 700 tons' daily capacity. This might be termed standard practice for medium-grade amygdaloidal ores.

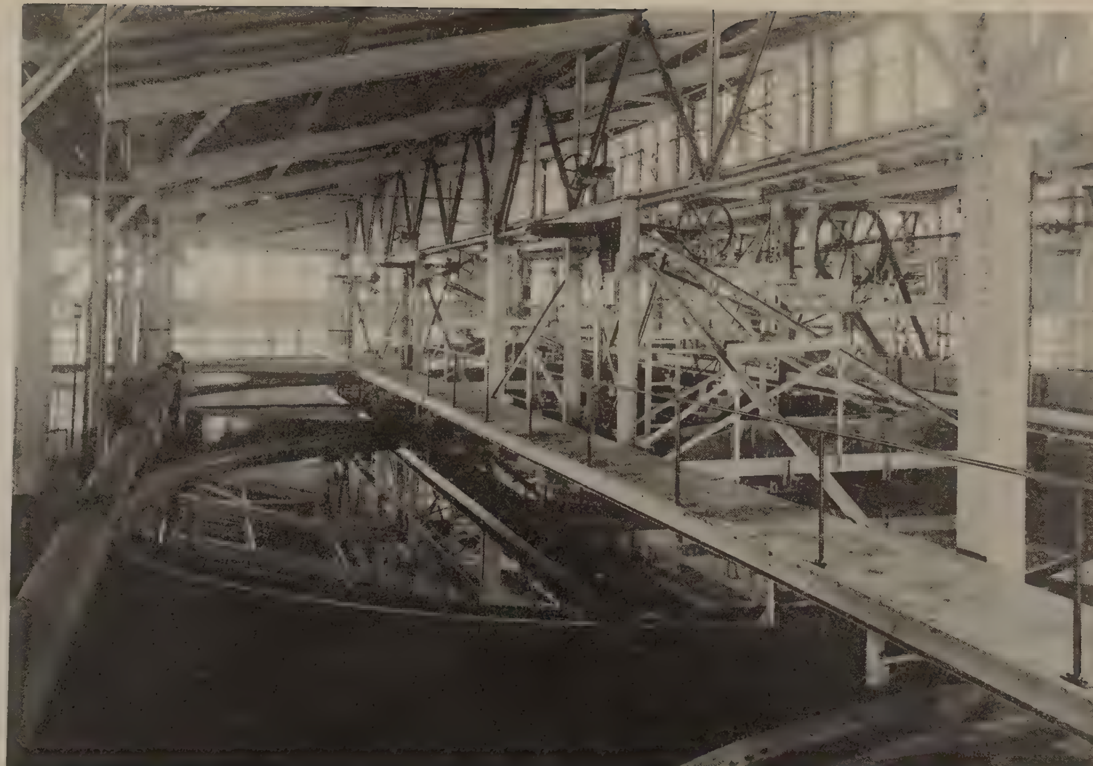
The Champion and the Baltic mills of the Copper Range Co. stamp the highest-grade amygdaloidal ores in the Lake Superior district, and in both there are enough ball mills in use to regrind all jig tailings. The Quincy plant has two Hardinge ball mills in operation and is now installing five Marcy ball mills for the regrinding of its jig tailings.

On the conglomerates ore of the Calumet and Hecla Mining Company, there are sufficient pebble mills in operation to regrind all jig and table tailings so that the product passes a 28-mesh screen and about 40 per cent passes 200 mesh. In all of the plants the product of the ball and pebble mills, with little preliminary classification, is treated on Wilfley tables, and a recovery of from 35 to 60 per cent of the copper is effected. The resultant tailings in all mills except those treating conglomerate ore are sufficiently low in copper to throw away. Only in the mills of the Calumet and Hecla does further metallurgical treatment follow the tables.

The conglomerate ore of the Calumet and Hecla Mining Company is in a class by itself, because of the fact that, as stated earlier in this paper, the copper is in a fine state of subdivision and also because the ore is richer than any of the amygdaloidal ores except the product of the Champion and the Baltic. The pebble mill regrinding followed by table treatment still left copper amounting to seven or eight pounds per ton, and it was realized that the limits in mechanical separation had been reached.

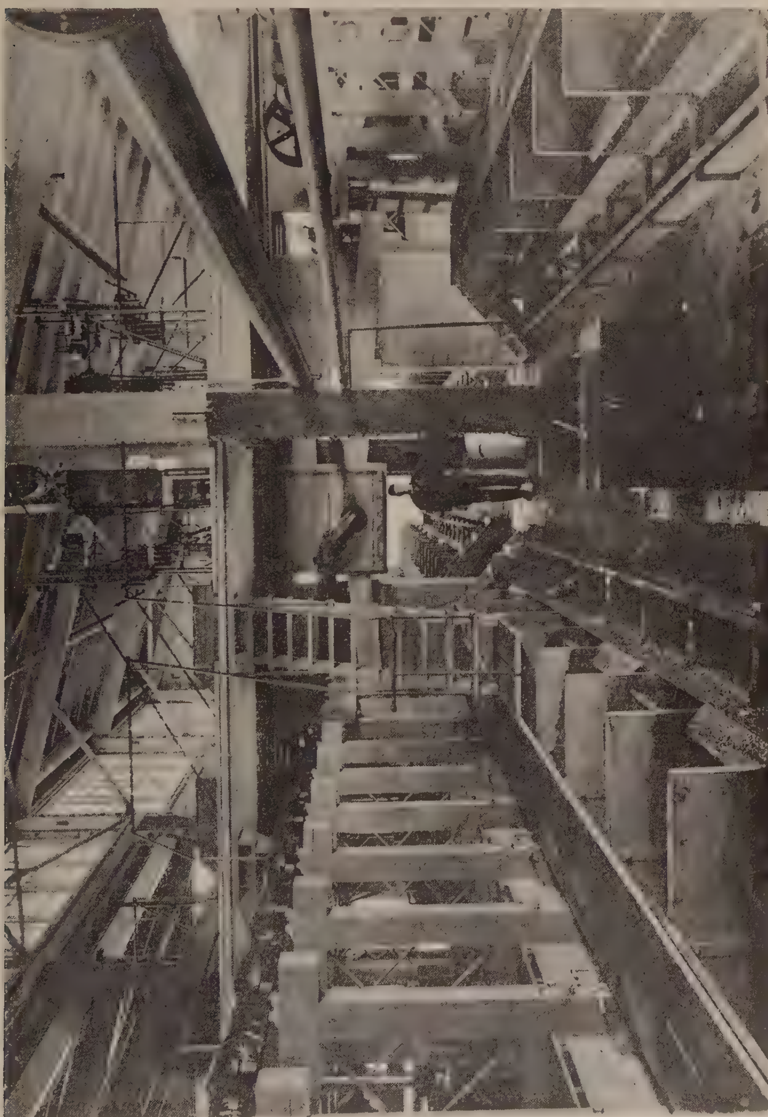
Efforts had been directed for many years to find a leaching method that would recover the copper commercially, and finally, in 1912, a process[1] was invented by C. H. Benedict which solved the problem. The leaching plant has now been in operation three years, and has been an entire success. For 1918 there was recovered 8,035,156 lb. refined copper from the treatment of 1,005,015 tons of sand, at a cost, excluding smelting and selling, of 7.71c

[1]Eng. Min. Jour., July 14, 1917.

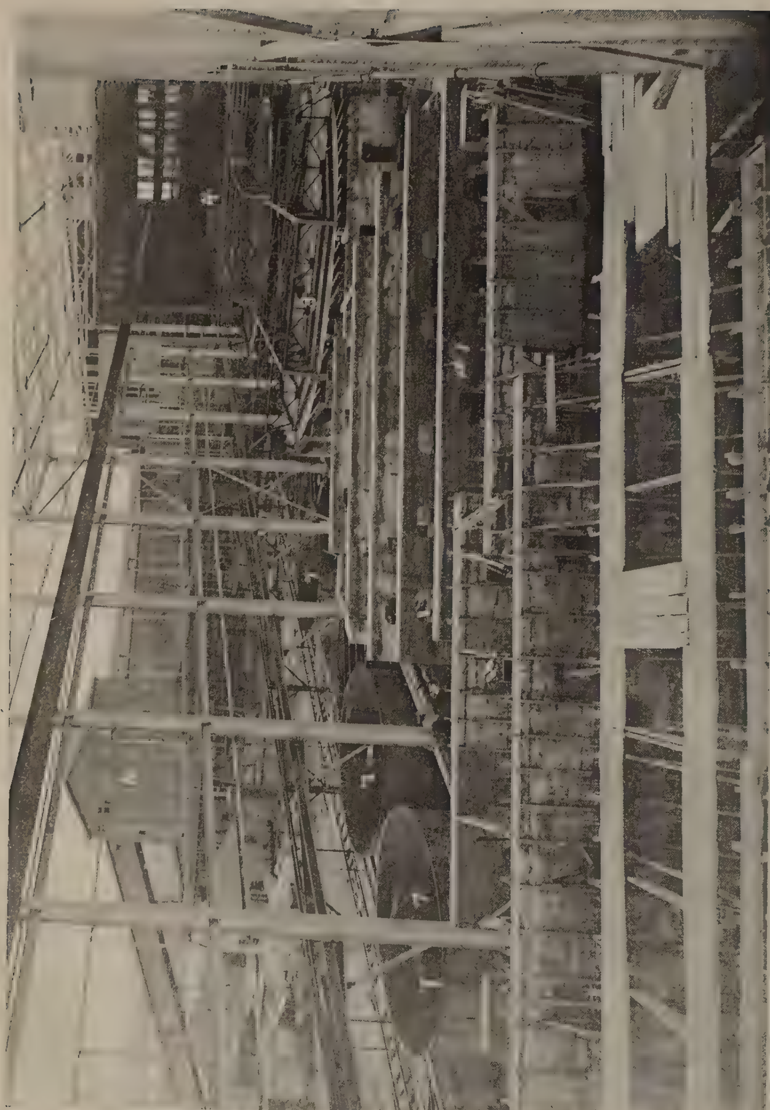


Flotation Plant, containing 8 three-tray Dorr thickeners, 40 feet in diameter. It has a daily capacity of 1,500 tons.

per lb. This showed a copper recovery of about 75 per cent on the material treated by leaching, and brought the recovery on the original ore up to better than 90 per cent. The cost of the leaching operation is about 40c per ton under normal conditions, which would necessitate a grade of ore assaying at least six pounds per ton before one could hope to make the process commercially available, and, as most of the amygdaloidal ores of the



Minerals separation flotation machines. Calumet & Hecla Company.



Leaching plant under construction. Calumet & Hecla Company.

district yield a tailing just under this, there does not seem to be much hope for the extension of the ammonia leaching process to such ores, although it is perfectly adaptable to them and will effect a good metallurgical recovery.

The latest development in the treatment of Lake Superior ores is the adoption of the flotation process. The leaching process has been worked out only for the treatment of the sands, and flotation is so efficient for the treatment of slimes that it is not conceivable that the leaching process could compete with it, even were the many mechanical problems worked out that would arise in an effort to adapt ammonia leaching to slimes. None of the amygdaloidal mines has installed the flotation process as part of the mill practice, although the Winona mill had made a beginning toward this end at the time it was closed down following the signing of the armistice.

Both the Copper Range and the Quincy are doing some experimenting with flotation, but neither company has even an experimental unit in operation. At the White Pine mill, where the ore is neither conglomeratic nor amygdaloidal, but consists of sandstone and slate, flotation is part of the regular practice, and all the tailings are subjected thereto. In this mill, the flotation is applied to the ore following the table treatment and as a final process. The ore consists of copper in a fine state of

Calumet and Hecla Smelter. General view looking North.

Calumet and Hecla Smelter Casting Building.

Electrolytic Plant of the Calumet and Hecla Mining Company. Located at Hubbell, Michigan, adjoining the smelter.

subdivision in sandstone, and in an almost microscopic state of subdivision in slate, so that the mill recovery, previous to the introduction of flotation, did not exceed 60 per cent. Flotation processes effect a recovery of about 65 per cent on the material treated, so that the final mill recovery is fairly satisfactory.

It is on the conglomeratic ore of the Calumet and Hecla Mining Company that the only flotation plant of any size is in operation. Up to the time of the introduction of flotation, slime practice had consisted of treatment of the pulp on round tables and of the concentrate produced by these on Wilfleys. This round-table Wilfley practice has now been discontinued, and the slimes, as they leave the Woodbury classifier following the stamp, are subjected to the action of a two-spigot hydraulic classifier following the stamp, and the resultant spigot products are treated on Wilfley tables. The overflow of this classifier goes to a 25 foot diameter three-tray Dorr thickener, and the product of this thickener is treated in flotation machines of the Minerals Separation type. For each conglomeratic-ore stamp unit of 350 tons daily capacity there is one 25 foot thickener, and the thickened product from four thickeners, amounting to about 400 tons daily, is treated on a 24-inch Minerals Separation machine of 600 tons nominal capacity. Of the sixteen cells of this Minerals Separation machine, two are used for mixing only, and two for cleaning up the concentrates of the other twelve.

The concentrates go to a Dorr thickener, and from this to an Oliver filter, from which the material is scraped into the concentrate cars for treatment at the smeltery. The plant has been working for about a year and indicates a recovery of about 65 per cent of the contained copper and at a cost of possibly 20 cents per ton, including royalty. In addition to this plant of 2,000 tons daily capacity on the Calumet and Hecla conglomerate, a second plant of like capacity is being built, which is to treat the slimes resulting from the regrinding operations, both of the current tailings and of the tailings from the lake. This plant will consist of eight Dorr thickeners, 40 feet in diameter, three-tray, and for the treatment of the thickened product will have four Minerals Separation type machines of 600 tons nominal capacity each. The plant should be in operation some time during the summer and will give a total flotation capacity of 4,000 tons. The capacity of the leaching plant is also 4,000 tons, so that the combined re-treatment plants will be able to handle the normal production

of 5,000 tons daily of ore from the mine and 3,000 tons from the accumulated tailings.

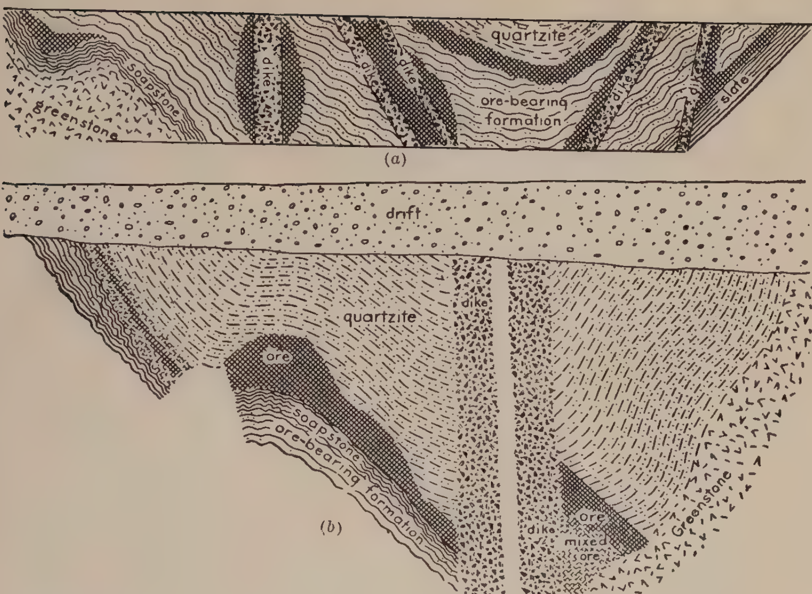
With the successful working out of the leaching and flotation processes on native copper ores, the operator in the Lake Superior copper region has at his command all necessary means for good metallurgical recovery. Milling costs are low, and can be lowered by cheaper power resulting from a more general installation of low-pressure turbines, which have been found universally satisfactory. Grinding costs may be still further reduced by improvements in machines or methods. Neither jig nor table practice has been improved for some years, the re-treatment of the tailings from these machines making them of less importance than formerly. It is to the economics of the problem that the mill man must give greatest attention.

THE MARQUETTE IRON DISTRICT.

Location: As shown on the accompanying map, the Marquette district extends from the region of Marquette on Lake Superior westward for about forty miles. The main basin of the district is only about three to six miles wide, but outlying areas which are commonly regarded as belonging to the same mining unit, make the north and south dimension of the district about twenty miles. The most productive portion of the area is in the vicinity of Negaunee and Ishpeming, about ten miles from Marquette, but important mines are found also all along the range as far west as Michigamme and also to the south in the fold known as the Republic Trough. Comparatively recent developments indicate that important ore bodies have been developed in the outlying Swanzy district about eighteen miles nearly due south of Marquette.

The Marquette Iron District.

History: The first discovery of iron ore in the Lake Superior region was probably that made in 1844 near the site of Negaunee by the government surveying party in charge of William A. Burt, sent out under the direction of Douglass Houghton. This surveying party was using a solar compass, invented by Mr. Burt, and noticed variations in the direction of the magnetic needle at various times and places, but on the 19th of September, while running the east line of Township 47 North, Range 27 West, the needle varied from its normal position until it stood nearly at right angles thereto. This caused a search in the vicinity and numerous samples of magnetic iron ore were promptly



Vertical sections through ore-deposits of the Marquette District.

discovered. Nothing but exploratory work was done during the next few years, and in 1848 the first iron ore was mined and hauled by team to a forge which had been constructed near Carp river. The project was not successful and terminated in 1850. The Marquette Iron Company opened the Cleveland mine near the present town of Ishpeming in 1849 and carted its ore to a forge at Marquette. At the end of five years this project also failed. In 1850 and again in 1852 a few tons of ore were shipped from the district to Pennsylvania furnaces, but these were merely in the nature of experiments. With the opening in 1855 of the ship canal along St. Mary's river, now known as the Soo Canal, larger shipments became possible and six thousand tons were sent east the next year. In 1857 a railroad was completed from Marquette to the mines and the shipments amounted in the following year to 23,000 tons. However, the mines did not obtain close relations with the iron furnaces and iron markets until the great demand for iron created by the outbreak of the Civil War. This resulted in an increase in shipments from 49,000 tons in 1861 to five times that amount in 1864, the companies meanwhile making such large profits as to firmly establish the industry. The shipments increased rapidly from 1866 to 1873, when there was a severe setback as a result of the panic of that year. In 1872 the

Republic, Michigamme, and Spur mines were opened, thus completing the development of the main portion of the Marquette iron district as known at present, although the Swanzy district, first explored in 1869, was not opened up by systematic drilling until 1902. Activity in the district has varied with the general prosperity of the country, but on the whole the production has increased steadily to the present time.

Geology: The Marquette district is divided from the Menominee district to the southward by structural folds, notably in the region of Republic and the adjoining territory to the west, but geologically the Marquette and Menominee districts are probably two parts of a single unit. The chief structure of the Marquette district is a great canoe shaped basin which comes to a point at the east end of the district, but is not terminated in any such simple fashion at the west end. Superimposed upon the major folds are smaller ones of varying size downward to minute plications, but all of the folds are definitely related to the major structure. The axial planes of the minor folds converge downward, their position having been determined by differential movements in the less folded and more competent intervening beds. In general, the highly folded layers consist of slate, while the more competent beds are quartzite. This structure is seen very plainly in the region west of Ishpeming.

In spite of this complexity, the geological succession has been worked out more fully in the region of the Marquette mines than elsewhere in the Lake Superior area, although recent work in the Menominee district by the State Geologist of Michigan suggests the existence of still greater complexity in the geological succession in that area. In the Marquette district the rocks are referred chiefly to the Huronian series, which is here divided into three portions as follows:

Upper Huronian (Animikie Group): Greenstone intrusives and extrusives. Michigamme slate (slate and mica schist), locally largely replaced by volcanic Clarksburg formation. Bijiki schist (iron bearing). Goodrich quartzite.

Unconformity.

Middle Huronian: Negaunee formation (chief productive iron-bearing formation). Siamo slate. Ajibik quartzite.

Unconformity:

Lower Huronian: Wewe slate. Kona dolomite. Mesnard quartzite.

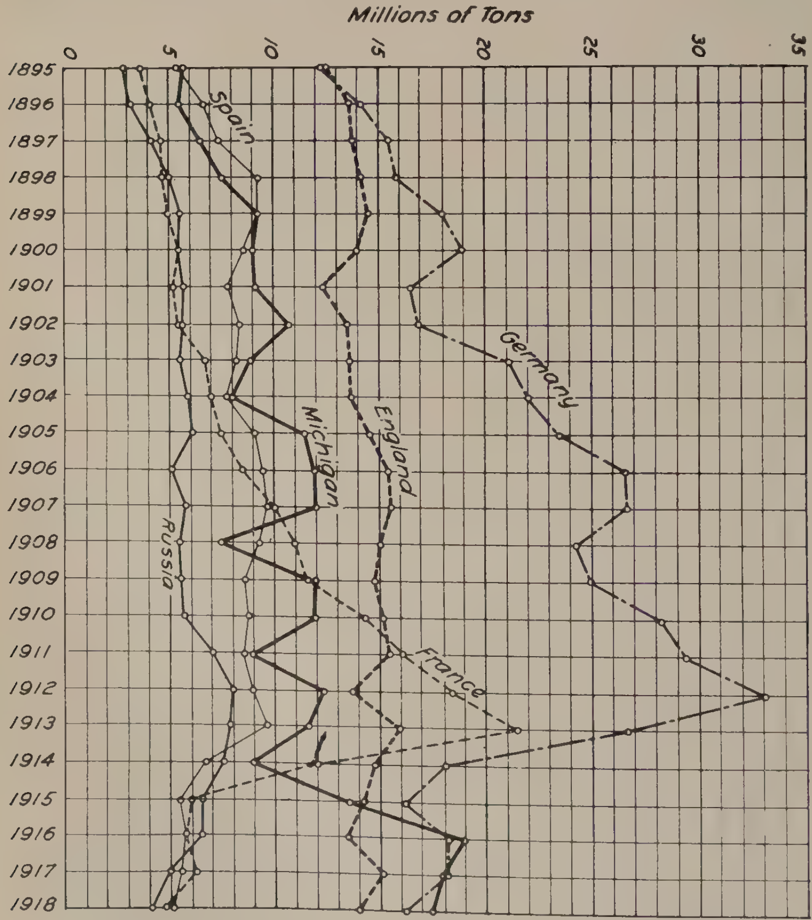
Unconformably below the Lower Huronian are formed the granites and gneisses of the Laurentian which intrude the Kitchi and Mona schists of the Keewatin.

As indicated above, the chief iron bearing formation is known as the Negaunee. It extends from the northwest end of the district along the north side of the Huronian belt to the northern border of Michigamme Lake. From this place eastward for a distance of five miles, the formation is cut out by an unconformity. Near Ishpeming it widens into a broad area occupying

Monument commemorating the first discovery of iron ore in the Lake Superior district in 1845, at the Jackson Mine, Negaunee, Michigan.

a large portion of two townships from which irregular arms extend to the east and a long belt to the west on the southern side of the Huronian. This formation is composed largely of slates containing cherty iron carbonate with more or less grünerite, magnetite, hematite or limonite. The ferruginous cherts and jaspilite are commonly brecciated. The thickness of the formation is estimated to reach a maximum which may be 1,000 feet.

Origin of Ores: The precise manner and cause of deposition of the original iron formation, including more or less lean iron ore, may be a matter of speculation, but the concentration of the ore through later alteration is known in detail. This alteration began during the middle Huronian period when the formation



Production of iron ore in Michigan compared with the output in the chief foreign countries, 1895-1918.

had been slightly folded, eroded, and intruded by igneous rocks. Prior to Upper Huronian time all the phases of the iron bearing formation now known except the specular hematite had been developed, for all of them appear as pebbles in the basal conglomerate of the Upper Huronian. The chief changes produced by this alteration were the conversion of iron carbonate into hydrated iron oxide and the removal of much of the quartz, thus raising the material from lean ore to high grade iron ore. There was considerable simultaneous replacement of silica by iron oxide. The

Lake Superior & Ishpeming Railway Company's concrete ore dock at Presque Isle near Marquette, Michigan.

only other change of importance which some portions of these ores have undergone is the elimination of water of hydration, producing the so-called hard or specular ores.

Production: Aside from small tonnages which may be regarded as mere experimental shipments, production on the Marquette range began in 1856. No other iron district in the Lake Superior region was productive until 1877 when the first mines were opened in the Menominee district. In this period of twenty-one years, nearly ten million tons of iron ore were produced from

Carp River hydro-electric power plant of the Cleveland-Cliffs Iron Company near Marquette.

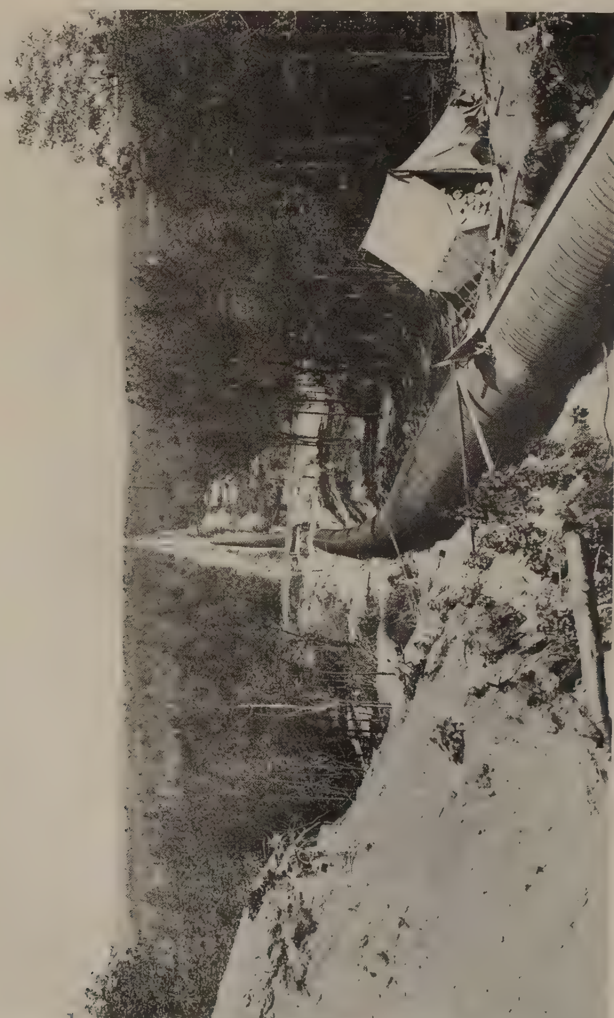
the Marquette district and this district yielded the largest annual production in the Lake Superior region each year until 1892. Up to January 1, 1920, the total output from the Marquette range was 131,512,722 tons, which is more than ten million tons greater than the total output of the Menominee district and is exceeded only by the output of the Mesabi district, although the Mesabi, Menominee, and Gogebic districts have all passed the Marquette in productiveness during the last ten years.

Mining Engineering Features: The mining methods vary. Ore caving as described for the Menominee range is the prevail-

McClure hydro-electric power plant of the Cleveland-Cliffs Iron Company on Dead River north of Marquette, Mich.

ing method. There is a limited amount of shrink-stoping. A considerable amount of mining by the milling system is carried on. The following brief descriptions and discussions of the engineering features in connection with operations on this range are given by the Cleveland Cliffs Iron Company, who have also furnished the illustrations.

The present No. 2 ore dock of the Lake Superior and Ishpeming Railway Company was erected at Presque Isle near Marquette in 1912, of steel and concrete construction. It is 1,200 feet long, 54 feet wide and 75 feet high from water to deck of dock and



Pipe line from the dam to the McClure power plant on Dead River, Cleveland-Cliffs Iron Company.

43 feet from water to hinge hole of spouts. It has 200 pockets and a storage capacity of 50,000 tons with a working capacity of 49,000 tons. The dock and the approach (672 feet long) contain 6,000 tons of steel; 34,000 cubic yards of concrete; 12,000 round and sheet piles and 600,000 cubic yards of earth. It was first used commencing with the opening of navigation in 1913. Total shipments from Presque Isle to end of 1919 are 38,167,169 tons of iron ore.

Surface equipment of the Negaunee Mine of the Cleveland-Cliffs Iron Co.

The Carp River hydro-electric power plant of the Cleveland-Cliffs Iron Company, near the mouth of Carp River, Marquette, was constructed in 1911 and put into operation in March, 1912. It consists of two 4,000 H. P. Francis Turbines connected to two 2,800 K. V. A. generators with suitable transforming equipment for line current of either 30,000 or 60,000 volts. The Intake Dam is situated at an elevation of 620 feet above the lake with an effective head of about 600 feet. The pipe line is 21,500 feet long, consisting of 10,700 feet of wood stave pipe 60 inches in

The Steel ore trestle of the Negaunee Mine of the Cleveland-Cliffs Iron C

diameter, 8,567 feet of 66-inch lockbar steel and 2,233 feet of welded steel.

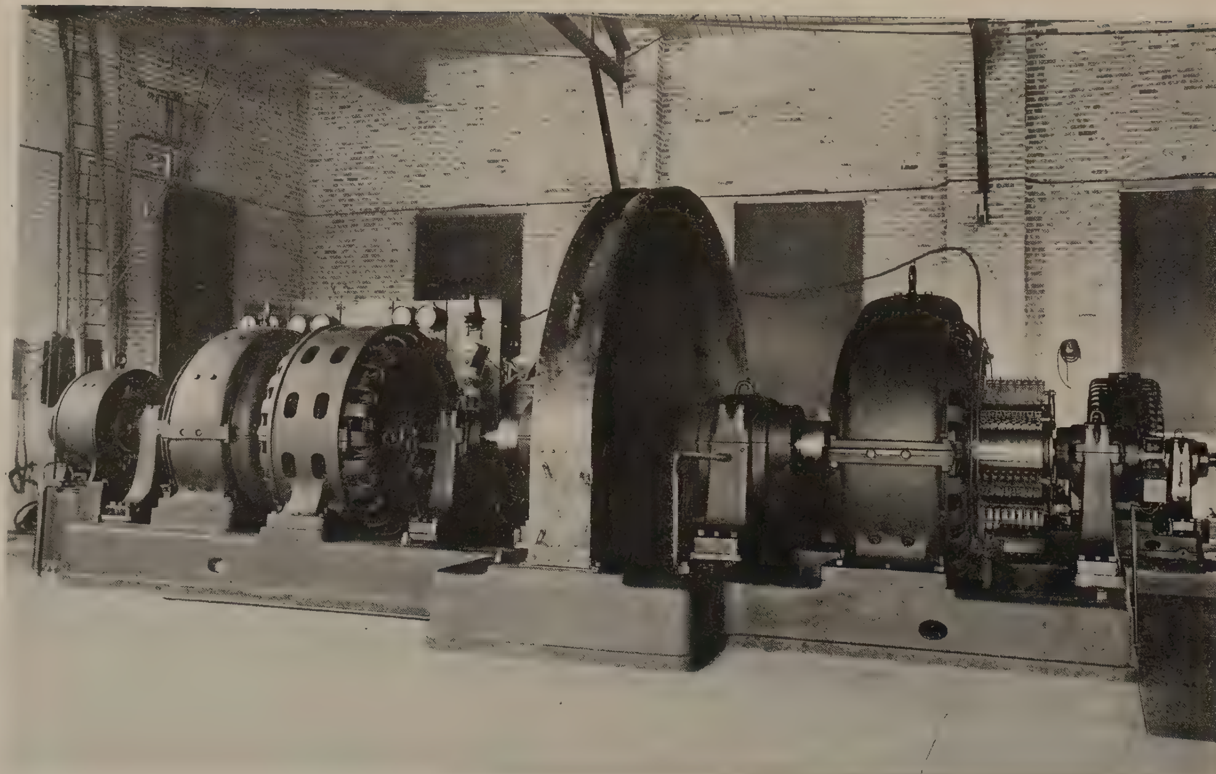
The transmission line comprises twenty-six miles of steel tower lines with four substations for distribution. The transmission line has been extended so as to reach all of the Cleveland-Cliffs Iron Company's mining operations on the Marquette Range.

The McClure hydro-electric power plant of the Cleveland-Cliffs Iron Company is on Dead River, north of Marquette. Work was started in October, 1917, and the plant was put in service February 5, 1919. It consists of two 5,000 K. V. A. generators controlled by a five-panel switchboard. Oil circuit breakers on generators and high tension lines are electrically operated. The substation is a steel structure with two three-phase, 2,300 to 30,000 volt, 5,000 K. V. A. transformers and two electrolytic lightning arresters.

The water wheels are 6,500 H. P. each, designed for 400 foot head at 600 R. P. M. and are horizontal type single runner turbines.

The pipe line from the dam to the power house is 84 inches in diameter. There are 3,600 feet of steel pipe and 9,700 feet of wood stave pipe. The transmission line from the McClure plant has been connected with the lines previously built from the Carp River plant, which lead to all the company's mines in Marquette County. Connected with the same system are smaller hydro-electric power plants situated at the Hoist Falls on Dead River, on the Au Train River in Alger County, and on the Michigamme River at Republic.

The Negaunee mine was first opened in 1887. The Cleveland-Cliffs Iron Company took over the management in 1904. In 1909 it was found necessary to sink a new shaft. The improvements on surface at the site of the new shaft were constructed between that date and 1913. The shaft is circular and 17 feet in diameter and lined with concrete. It is 1,086 feet deep. The head frame and stocking trestle are all of steel. The mine buildings are of brick construction. They consist of engine house with electrical equipment, dry, office and laboratory. In the foreground are the shops and warehouse. These and the timber yard are connected with a track which passes under the stockpile grounds in a concrete tunnel. This tunnel serves also for an outlet for the men and a covered stairway connects it with the dry. The quipment has proved sufficient for an output of 50,000 tons a month.



The motor generator set of the Negaunee Mine of the Cleveland-Cliffs Iron Company.

The Negaunee mine steel ore trestle, constructed in 1912, is a permanent trestle and designed so that practically all the ore in stock can be removed by steam shovels. The trestle is 42 feet high and is supported by reinforced columns of steel at intervals of 114 feet. The columns are 6 feet in diameter at the base and 4 feet at the top; they are supported by pyramid-shaped reinforced concrete bases 12 feet by 26 feet and 6 feet deep. The reinforcement is made with ⅞ rods which extend up the column for a height of about 20 feet.

Surface equipment of the Athens Mine of the Cleveland-Cliffs Iron Company looking North.

The trestle was built under a guarantee to support a movable load of ten tons. The gauge of the double tracks is 30 inches. The distance between centers is 20 feet. The plate girders are made up of angles and two plates 42 inches wide and ¼ inch thick.

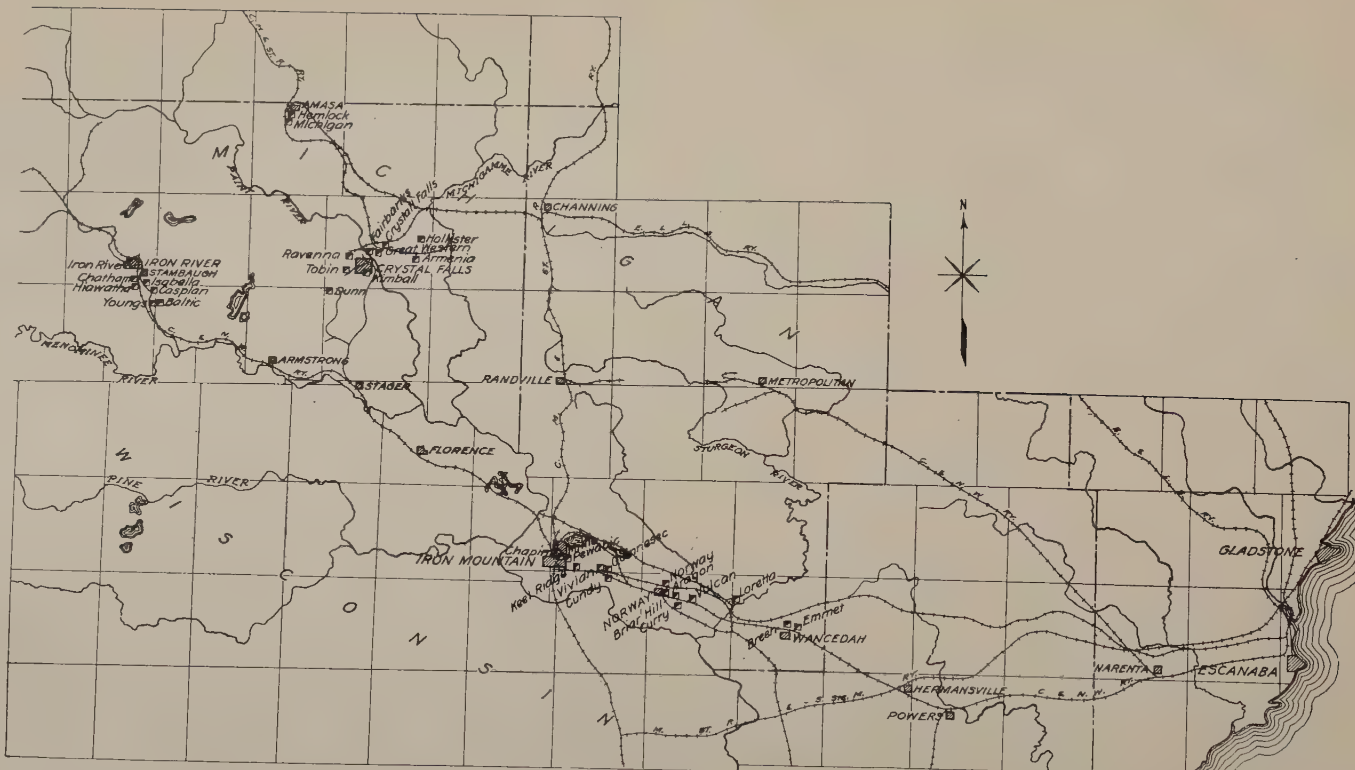
The length of the trestle from which ore can be stocked is 2,094 feet. The capacity is 340,000 tons.

The Negaunee mine motor generator set has a 350 H. P. induction motor, a 400 K. W. 600 volt direct-current generator,

Ishpeming Hospital of the Cleveland-Cliffs Iron Company and the Oliver Iron Mining Company.

a 25 K. W. 200 volt exciter and a 25,000 lb. flywheel mounted on one shaft. The direct-current generators are connected directly to a 500 H. P. 600 R. P. M. first-motion hoist motor for ore skips, and to a 200 H. P. 250 R. P. M. motor with helical gears for the cage or man hoist. The flywheel set has an automatic slip regulator, which by an automatic changing of the resistance in the rotor of the induction motor, gives a variation of speed from 550 to 720 R. P. M. depending upon the load. The armatures of the generators and hoist motors are connected directly by 1,000,000

Concrete shaft and house at the Cliff Shaft Mine of Cleveland-Cliffs Iron Company.



Map of Menominee district showing location of mines.

C. M. cables without intermediate circuit breakers, the motors having constant excitation in the fields and the control is by varying the field of the generators. The ore hoist is designed for a 90 second cycle under a 1,000 foot hoist and gives a maximum hoisting speed at full load of 1,500 feet per minute.

The Athens mine shaft was sunk between June, 1913, and May, 1917, to a depth of 2,480 feet. It is lined with concrete and has steel dividings, etc., similar to those at the Negaunee mine. The surface equipment is of fireproof construction and the machinery is all electric. The only coal used is for heating. The general plan of the buildings is similar to that of the Negaunee mine.

The Ishpeming hospital was completed in October, 1918. The construction throughout is fireproof. The building is 144 feet long and its width is 47 feet. There are three stories besides the basement. Beds are provided for 50 patients, most of them being in private rooms. The equipment in every respect is complete and up to date. Though the hospital was erected by the Cleveland-Cliffs Iron Company, it is supported jointly by the Oliver Iron Mining Company and the Cleveland-Cliffs Iron Company.

The new concrete shaft house at the Cliffs Shaft Mine at Ishpeming shown in the accompanying print was built in the fall of 1919. A similar one was built at "B" shaft house. These structures were built outside of the old frame shaft houses while in use. This construction is described by Mr. Lucien Eaton, Superintendent of the Cliffs Shaft Mine, in his article on this subject which will be read at the forthcoming meeting of the American Institute.

THE MENOMINEE IRON DISTRICT.

Location: The Menominee district has been described geologically in several units, because the known iron-bearing formations of the larger region are not areally connected. From the commercial and mining standpoint, however, the district embraces all that territory extending from a point about five miles east of Vulcan to a point a few miles west of Iron River, an east-west distance of about fifty miles, and from a line about two miles south of Vulcan to one ten miles north of Crystal Falls, a north-south distance of about thirty-five miles. This area is largely in the State of Michigan, but includes more than two hundred square miles in Florence County, Wisconsin. The chief

towns of the district are Vulcan, Iron Mountain, Iron River, and Crystal Falls, in Michigan, and Florence in Wisconsin. The Wisconsin portion of the district has not produced a large portion of the output of the area.

History: The earliest reports of iron ore in the Menominee district were made by J. W. Foster and S. W. Hill, who conducted a geological exploration from Lake Superior to Green Bay in the fall of 1848. It is a remarkable fact that in spite of their plain statements regarding their discoveries, these statements were apparently forgotten for a period of nearly twenty years. Foster states that "about two miles southeast of the lower falls (of the Twin Falls on the Menominee River) near Sec. 30, T. 40 N., R. 30 W. there is a large bed of specular iron ore associated with the talcose and argillaceous slates. It makes its appearance on the north side of the Lake and can be traced a mile and a half in length and in places is exposed one hundred feet in width."

Foster compared this ore with that of Elba, New York, and Missouri, and called attention to the fact that the natural outlet would be by way of the port now called Escanaba, on Lake Michigan.

Col. Charles Whittlesey in the "Report of the Commissioners of the Geological Survey" of Wisconsin for 1858 gives another account of the iron ores of the Menominee River as follows: "In 1850 I passed up the Menominee as far as Irwin Falls and examined the rocks to the east of the river in Michigan. Here the magnetic and specular ores were found, and beautifully veined marbles. * * * During the explorations of the present year, in tracing that system [Magnesian slates] within this state across the Menominee River, I had the satisfaction to find that it produces here both iron and marble in quantities that are inexhaustible."

The report of Foster and Whitney on Lake Superior in 1851 again records specular iron on the Menominee River, but it was not until 1866 that Thomas and Bartley Breen made the first discovery of iron ore which was followed by practical exploration. More serious development work was done by N. P. Hulst for the Milwaukee Iron Company at the Breen and Vulcan mines in 1872, and by John L. Buell at the Quinnesec the following year. The existence of ore in shipping quantities was demonstrated as early as 1874, but the lack of transportation facilities prevented further development until the Northwestern Railroad was built

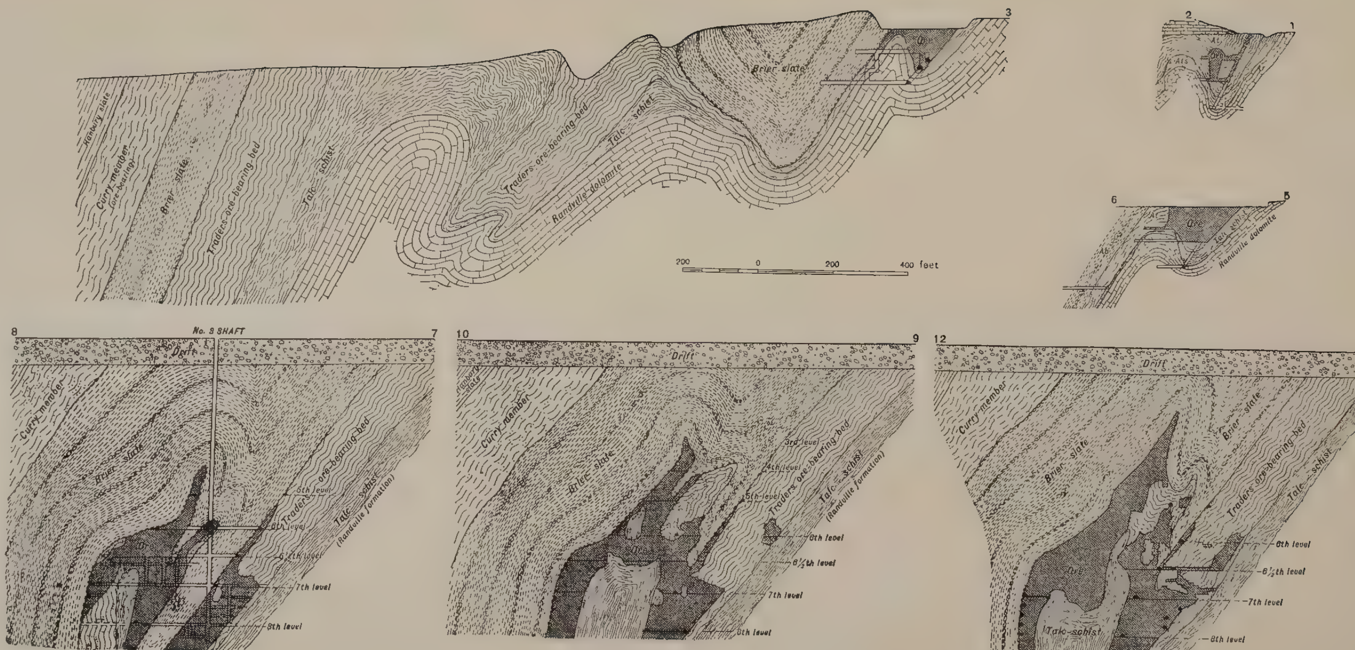
from Escanaba to Quinnesec. This was extended to Iron Mountain in 1880 and shortly afterward to Iron River and the Gogebic Range. The Chicago, Milwaukee and St. Paul Railroad entered the district in 1886 and the Wisconsin and Michigan in 1903.

For some time after the opening of the Menominee district prospectors explored regions in the general vicinity, and as a consequence of the attempt to follow the iron ores westward the deposits at Florence, Wisconsin, and then those still farther away at Crystal Falls, Michigan, were discovered. By the year 1881, the latter area had been explored sufficiently to lead to the extension of the Northwestern Railroad to Crystal Falls, early in the following year. The Amasa deposits were not opened until 1888, when the railroad was extended from Crystal Falls to this point. Five years later the Milwaukee Railroad completed a branch line to the same point.

Shipment of ores began promptly after the completion of the first railroad in 1877 and increased much more rapidly than in the case of the early development of the Marquette district.

Production. The production of iron ore from the Menominee district began in 1877, with a shipment of 10,405 tons; it increased rapidly to more than a million tons in 1882. On account of industrial depression, the output amounted to less than 700,000 tons in 1885, but exceeded a million for the second time in 1887 and passed the two million mark in 1890. The depression in 1893 led to an output of about one million in 1894, followed by a rapid and fairly steady increase to 4,600,000 tons in 1902. Since that date, the output has been from three to five million tons, except during 1916 to 1918, when war demands increased the output to more than six million tons. The total aggregate production of the district to January 1, 1920, is 120,474,574. The relative importance of the district as compared with other iron districts of Lake ore is shown graphically on page 186.

Geology. As in the case of the other iron bearing formations of the Lake Superior district, the iron ores on the Menominee range are found in rocks of pre-Cambrian age, referred to the Huronian series. The oldest rocks of the district are greenstone schists which are classed as Keewatin. These are intruded by Laurentian granites and gneisses which are in turn cut by later dikes of granite and diabase. Upon this complex of schists, gneisses and granites, the overlying Huronian sediments were unconformably deposited. The Huronian series is divisible into at least three parts known as Lower, Middle, and Upper, but the



Vertical North-South Sections through the Vulcan-Norway Area illustrating Geological structure in the Menominee District, Michigan, reproduced from Monograph 46, United States Geological Survey, by W. S. Bayley.

precise classification of the sediments present is a matter upon which agreement has not yet been reached. The following table exhibits the succession as given by Van Hise and Leith in the Lake Superior Monograph in 1911 and the classification of the same sediments as worked out by R. C. Allen, State Geologist of Michigan, in 1915 to 1919.

Geological Column in the Menominee District.

Van Hise-Leith, 1911		R. C. Allen, 1919
Upper Huronian	Quinnesec schists (Volcanic) Michigamme ("Hanbury") slate (very thick)	Upper Huronian
	Loretto slate (Allen) Vulcan formation Curry iron-bearing Briar slate Traders iron-bearing	Middle Huronian
Middle Huronian	Quartzite (V. H.-L.)	
Lower Huronian	Randville dolomite Sturgeon quartzite	Lower Huronian

Laurentian granites cutting Keewatin schists

The general structure of the Huronian formation of the Menominee district is complicated, but characterized by close folding so that many of the beds are now nearly vertical, and continuous exposures are not always known on account of the complexity of the folding and faulting. The chief iron-bearing horizons are found in the Vulcan formation which is correlated by Allen with the Negaunee iron-bearing formation of the Marquette district.

Ores. Much the larger portion of the ore in the Menominee district has been obtained from the Traders iron-bearing member of the Vulcan formation. The ores are chiefly found near the foot and hanging walls of this member, but in some cases large ore bodies extend entirely across the members in which they occur. The larger deposits are commonly found resting upon

relatively impervious rocks which are folded, or less commonly faulted in such a way as to constitute pitching troughs. The impervious formation may be the Randville dolomite underlying the Traders iron-bearing member, or a slate constituting the lower part of that member, or the Briar slate member underlying the Curry iron-bearing horizon. Where these underlying rocks have been transformed in their upper portion into a talc schist they are particularly impervious and therefore favorable to the formation of ore. The wall rocks of the ore bodies may be unaltered phases of the iron-bearing member, such as ferruginous cherts, or any of the rocks forming the impervious layer. Small ore deposits are found at contacts between the different members and at places within the iron-bearing members which have suffered faulting and brecciation. Such deposits are notably irregular, forming commonly broad sheet-like masses of vague limits and especially uneven along their upper surfaces.

The ores are associated with marked topographic relief which may have had some effect in affording abundant head for the circulating waters which have been responsible for the secondary concentration. The iron-bearing formation was originally cherty iron carbonate and greenalite interbedded with slate and containing fragmental iron oxide at the base. The alteration of this formation resulting in a secondary concentration of the iron ore has been accomplished by three distinct processes, namely, oxidation and hydration of the iron minerals, leaching of silica, and the transfer of iron oxides and iron carbonate from one part to another in the formation. The first process was far advanced before the second and third became conspicuous. The earliest products of alteration are therefore ferruginous cherts which are commonly too low grade for mining. The removal of the silica in solution with more or less transfer of iron compounds to the zone of enrichment is necessary to produce the ore.

A general statement concerning mining on the Menominee range has been prepared by various operators and is given below.

Commonly, in mining literature, the Menominee iron range is spoken of as including the Iron River, Amasa, Crystal Falls, Alpha, and Florence areas, as well as the area extending from Iron Mountain east to Waucedah. The several areas west of Iron Mountain are important producers of iron, and have many interesting features, but the central part will receive chief attention here.

Before the Menominee iron range was discovered Menominee and Marinette were frontier towns from which explorers set out into the wilderness to the north. Beyond the wilderness were the Marquette iron range and the copper country, both of which were reached by boat. A trip from the copper country to the Menominee area was not the easy trip of a few hours on a railway train that it is today. The easiest approach was from the south and the result was that the iron range was explored from east to west. The members of the A. I. M. E. having reached the range at the point where the explorer finished his work, will find it convenient to travel in the opposite direction from which he traveled. The pioneer of the range was obliged to travel on foot or by canoe routes and pack his belongings on his back; later he had the use of crude wagon roads, and then the railway. Today we are able to speed along over the same area in automobiles.

For many years the falls and rapids of the Menominee River and its tributaries were valued only for their scenic beauty, but in more recent years plants have been built to develop the power and transmit it to the surrounding cities and mines. Four miles north of the city of Iron Mountain, at Twin Falls, is one of the plants of the Peninsular Power Company. Another plant belonging to the same company is located is located north of Florence on the Brulé River. The Twin Falls plant was finished in 1912. It has nine units developing 1,200 k.w. each; the Brulé plant was completed in 1918 and has two units of 2,000 k.w. each; a third unit is being installed. The main trans-

Peninsula Power Company hydro-electric plant at Twin Falls, four miles north of Iron Mountain, Michigan.

Oliver Iron Mining Company Power Plant at Big Quinnesec Falls, two miles south of Iron Mountain, Mich.

mission line carries 66,000 volts. Power is supplied to about thirty mines from Iron River to Loretto and practically all the towns in the same area are lighted by the current supplied by the Peninsula Power Company. This is the only company in the area that sells power. There are several other plants, but the companies that own them use the power that is developed.

The Chapin mine, which was discovered in 1879 and shipped its first ore in 1880, is located at Iron Mountain. The present Chapin mine includes what were formerly four independent mines: the Chapin, Hamilton, Ludington, and Millie. The deposit is the largest on the range, and soon after its discovery the mine

Penn Iron Mining Company Hydro Electric Plant, Sturgeon Falls, Menominee River.

oecame, and has since continued, one of the premier mines of the country. The ore body is such that it presented many new and unusual features in mining, and several methods were tried before the ore was cheaply and efficiently mined.

The early methods of mining at the Chapin required a large number of shafts, nearly all of which are now abandoned, only three remaining in use. Of those that are abandoned only "D" Chapin need be mentioned, and that merely because of the freezing method used to penetrate the surface material covering the rock.

Hamilton No. 2 shaft was one of the early shafts of the mine and it is yet in use. It was originally lined with timber, but that was recently removed and concrete put in its place. The shaft is watertight from top to bottom.

The Chapin mine water is handled by centrifugal pumps stationed at the twelfth and sixteenth levels of the Hamilton shaft. At the sixteenth level are two pumps, each having a capacity of 3,000 g.p.m. against a 400 foot head, and a third of 400 g.p.m. Only one of the larger pumps is in use at any time and the smaller pump is used to assist whichever larger pump is working. Each pump is driven by an electric motor. The pumps and station at the twelfth level are quite like those at the sixteenth, except that they are able to operate against a head of 1,000 feet. The pumps at the sixteenth level force the water to the twelfth level, from which it is forced to the surface. A large part, but not all, of the water of the Chapin mine can be seen entering the crosscut from a large natural opening a short distance south of the Hamilton shaft on the sixteenth level.

The Cornish pump at "C" Ludington shaft was originally installed at "D" Chapin, but when that shaft was abandoned the pump was stored for a time, after which it was set up in its present position, where it worked only a short time before the electric driven pumps were installed at the Hamilton shaft; since that time it has stood idle, or practically so. It is kept now only for use in case of accident to the other pumps. It has a capacity of 3,000 g.p.m. against a 3,000 foot head.

Attention should be called to the 1,600 k.w. steam turbine at the Hamilton shaft, to be used in case of trouble on the transmission line or at the power plant.

The Pewabic mine, which is also located at Iron Mountain, made its first shipments of ore in 1889. It worked continuously

from that date until 1918, when operations were suspended. It is claimed that the Pewabic mine was the greatest producer of high grade, low phosphorous ore in the United States. The ore body was covered by about 325 feet of flat lying rocks consisting of 225 feet of Cambrian sandstone and 100 feet of siliceous limestone. These flat lying rocks caved when the ore was removed from beneath, causing a cave at the Pewabic mine quite unlike any other along the range.

Immediately east of the Pewabic mine is the Keel ridge mine. Though this property is often spoken of, it was never a prominent producer of ore and was early abandoned.

South of Keel Ridge about two miles, at Big Quinnesec Falls, is the power plant of the Oliver Iron Mining Company. The compressor plant was completed in 1883, since which time it has supplied the Chapin mine with air at sixty-five pounds pressure. It is carried through a twenty-four inch pipe a distance of about three miles from the plant to the mine. The company also has an electric plant at the same falls which consists of two units. A line carrying 13,200 volts carries the power to the Chapin and Aragon mines.

East of Keel Ridge mine is the village of Quinnesec and the Vivian, Cundy and Quinnesec mines, all of which are now abandoned. Quinnesec was for a time during the early days situated at the end of the railway and was the metropolis of the range. Due to the fact that no large, high grade ore bodies were found there it soon gave place to other towns and became nearly abandoned, in which condition it remains today. The first ore shipped from the Menominee range was sent by Mr. John L. Buell from Quinnesec in the winter and spring of 1873-4. It was taken by sleigh and wagon to Menominee, a distance of about seventy miles, where it was smelted by the Menominee Furnace Company.

An interesting unconformity between the sandstone and the older formation is well exposed at the Quinnesec mine.

About two miles east of Quinnesec is the Section Six mine, which is interesting because it shows the iron bearing member exposed in a large open pit. It also shows that the Menominee iron range is able to produce a large tonnage of ore very cheaply by open pit mining.

The Aragon mine at Norway is the property of the Oliver Iron Mining Company. The first shipments were made in 1889. The mine is being electrically equipped, power being supplied from the company plant at Big Quinnesec Falls. Two air com-

pressors are already at work and supply air at ninety pounds pressure for the drills. Three centrifugal pumps, each with a capacity of 1,200 g.p.m. against a head of 1,365 feet, are being installed on the fourteenth level. The Prescott pumps which have been used for several years will be kept ready against accident to the new pumps.

Penn Iron Mining Company in 1882 took over a group of mines in Vulcan and Norway which had been opened by the Menominee Mining Company in 1877. The output at present is between 350,000 and 400,000 tons a year. The group of mines comprises East Vulcan and East Central with three shafts; West Vulcan, Curry and Briar Hill with three principal shafts, and the old exhausted Norway mine and explorations.

Electrical Equipment. The hydro-electric plant was constructed on the Menominee River between three and four miles from the mines in 1905-1907. The head is twenty-six feet and the horsepower obtained for the greater part of the year is about 2,650 horsepower. During low stages of water, the hydro-electric plant is supplemented by a steam turbine of 1,500 k.v.a. at one of the mines. The Penn group of mines was the first in the Lake Superior region to be fully equipped with electric machinery. This plant was described in a paper by T. W. Orbison and F. H. Armstrong, printed in the proceedings of the Lake Superior Mining Institute, Volume XIII, pages 153 to 181 (1908); in a paper by F. H. Armstrong in the proceedings of the Lake Superior Mining Institute, Volume XVI, pages 244 to 250 (1911), and a paper by William Kelly and F. H. Armstrong entitled, "Use of Electricity at the Penn and Republic Iron Mines, Michigan," and printed in the transactions of the American Institute of Mining Engineers, Volume XLVIII, page 262. Attention is particularly called to the following special features of the equipment:

Pumps. The main pumps are eight stage centrifugal pumps with a head of 1,200 feet. At West Vulcan the quantity of water is from 900 to 1,000 gallons per minute and at East Vulcan about 800 gallons.

Recording Water Gauge. A recording water gauge on the surface is used to determine the quantity of water discharged from the mine through a circular knife edge orifice.

Hoists. Geared hoists are driven by a motor by means of an endless rope drive and the drums are operated by a mechanical clutch and started when the motor and moving parts attached

are up to speed. One great advantage of this method is that the weight of the revolving parts outside the drum acts as a fly wheel and thereby eliminates any starting peak. When the drum is clutched in, the speed is slightly reduced, but within the slip speed of the motor. The mechanical clutches have been used in this way for thirteen years and very seldom require attention. The hoists at Curry and Briar Hill raise a load of six tons of ore from a depth of 1,600 and 1,300 feet, respectively, at a speed of 600 feet a minute. Each of the hoisting plants has two drums operated independently, one drum for an ore skip and one for a cage to handle men and timber. The skip drum for ore is operated with a counterbalance. The Curry hoist was designed by the company's mechanical engineer and constructed in the company's shops.

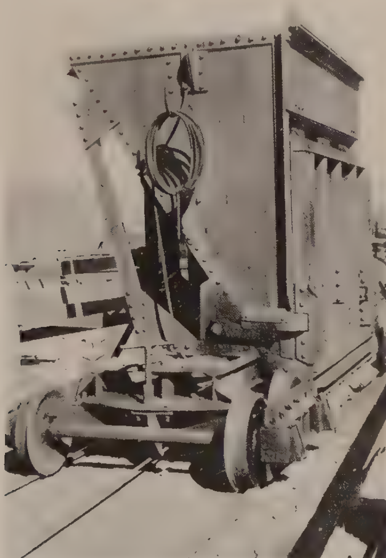
Counterbalances for Skips. At the Briar Hill plant, the counterbalance rope runs from a conical drum on the same shaft with the hoisting drum. In the Curry plant, the counterbalance rope is attached to the main cylindrical hoisting drum, but wound in the opposite direction from the skip rope, and passes from the main drum to one of a pair of conical drums, from the other one of which the rope leads to the counterbalance. By means of the conical drums, the counterbalances equalize the weight of the skips and the changing weights of the ropes at all points in the shafts, nearly equally reducing the load throughout and (a matter of the greatest importance) at starting. The travel of the counterbalance is less than that of the skip so that it does not rise to the collar of the shaft, thereby decreasing the danger from freezing.

Take-on-balance. In order to take the skip out of the dump, as it approaches the dump, a sheave on the bale engages a rope, one end of which is fixed and the other end runs over a pulley and carries a weight. The weight of this "take-on-balance" replaces the weight of the skip, which rests on the guides after it goes into the dump. This added weight overhauls the drum and permits the use of the maximum counterbalance weight.

Safety Device on Hoist. The safety device for the cage at the Curry hoist prevents the cage from going to the bottom or coming to the top landing unless the operator pushes a foot lever. It prevents also hoisting upwards from the top landing and applies the brake if the speed of the cage exceeds a determined rate. Demonstration of the efficacy of this safety device will be shown to visitors.

Water Rheostat Controller. At the Briar Hill hoisting plant the induction motor is operated by a water rheostat controller. The resistance is controlled by raising the plates from and lowering them into a tank of water.

Surface Tram System. The ore is trammed from the shaft to railroad pockets or to stockpiles by means of a car attached to an endless rope driven by a stationary motor, the motor being under distance control of the lander. The tram car consists of a box with an inclined bottom and a door on one side. The door is unlatched by a lever which at the dumping point is raised at



Penn Iron Mining Co., Vulcan, Mich. Surface Tram Car.

one end by a stationary block. The tripping device on the car can be placed at different elevations and tripped at the corresponding block so that several grades of ore can be unloaded at different points. One great advantage of this endless rope system is that no one has to go on the trestle except for oiling or repairs and it avoids the dangers of the use of a trolley locomotive on stockpile trestles. It is necessary to deposit the different grades of ore on a single line of track, though not necessarily a straight line, because it is not feasible to operate switches. In order to facilitate the rounding of curves, the car is supported on two four-wheel trucks with short wheel base.

Electro-hydraulic Shovel. The principal stockpile loader is an electro-hydraulic shovel which was described in the transactions of the American Institute of Mining Engineers, Volume LIV, page 100.

This shovel has the advantage of being operated by electricity, but without the complicated devices of the usual type of electric shovels, and, owing to the absence of boilers, drums and gearing, the wearing parts are reduced to a minimum.

Three Armstrong loaders are used underground for mucking the dirt in drifts. These machines were perfected here.

Concrete Lined Shaft. The Briar Hill concrete lined shaft is described in a paper printed in the proceedings of the Lake Superior Mining Institute, Volume XIV, page 140. The shaft is circular, fourteen feet in diameter, lined with concrete throughout and now 1,277 feet in depth. The concrete is without reinforcement and averages a little over thirteen inches in thickness.

Ore Pockets. At Briar Hill there are four ore pockets of about 100 tons capacity each to hold the ore to be loaded into railroad cars. These pockets are essentially tubs of steel with flat concrete bottoms and chutes with under-cut revolving gates. The pockets are directly over the railroad track and each is supported on four steel columns.

East Vulcan Change House. This is a small miners' change house of fireproof construction which uses the French system for drying and aerating the "digging clothes." The clothes are hung on hooks and hoisted by chains up into a steam-heated

Penn Iron Mining Co., Vulcan, Mich. Change House, East Vulcan Mine.

monitor for drying. This change house was described in the proceedings of the Lake Superior Mining Institute, Volume XVIII, page 213.

Briar Hill Change House. This is a fireproof structure of structural steel and "hyrib"-cement construction in which the digging clothes are hung in individual sheet steel lockers. Each double row of lockers is surmounted by a chamber formed by continuing the locker fronts up to the ceiling. This chamber has an outlet to a ventilator on the roof. Underneath the lockers are steam pipes. Each miner also has an expanded metal locker for his street clothes. In both change houses the men furnish their own pails for washing.

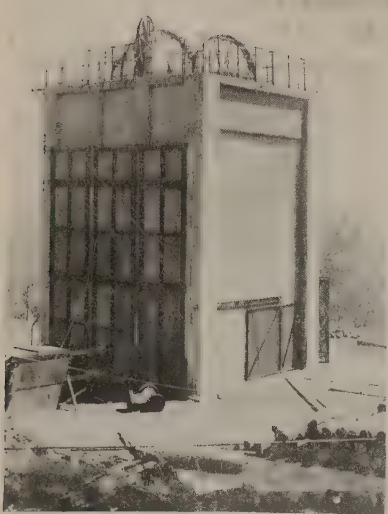
Briar Hill Hoist House. Briar Hill hoisting house as a structure is remarkable only by reason of its extremely thin concrete roof and side wall slabs. It is of structural steel framework supporting ferro-inclave for roof and side walls. This fabric was plastered with cement mortar outside to a depth of one inch and back plastered inside three-eighths inch, making a total of 1⅜ inches thickness.

Curry Hoist House. Curry hoisting house is a fireproof structure of steal and "hyrib"-cement construction. It was designed of minimum size to house a very compact hoist. It has only one entrance door and two large steel-sash windows—all in that side of the building which is back of the operators' platform, thus obviating glare in the men's eyes.

Curry Head Frame. At the Curry shaft is a tall steel head frame erected in 1908. In 1915 a gyratory crusher was installed at a height of thirty-five feet above the ground and to support it and the necessary bin and electric motor a reinforced concrete structure was built into and around the steel structure. Reinforcement was entirely of discarded hoisting ropes. The gate of the ore bin under the crusher is closed with a toggle joint.

Briar Hill Head Frame, Crusher Building and Equipment. At Briar Hill shaft there is a steel head frame, erected in 1909, and beside it stands a concrete structure which was built in 1915 for a crusher house. As there are different grades of ore, the six-ton skip loads are carried through the crusher as units. The concrete structure is ninety-six feet high above the ground and at its top supports a small electric hoist to raise a skip for the crushed ore from below the crusher to above the transfer car on the trestle level. By means of a counterbalance equal to the weight of the skip and half the load, and by a pulley system of

Penn Iron Mining Co., Vulcan, Mich. Ore Pockets, Brier Hill Shaft.



Pen Iron Mining Co., Vulcan, Mich. Concrete Head Frame, East Vulcan Mine.

Penn Iron Mining Company, Vulcan, Michigan. Concrete Head Frame West Vulcan Mine.

ropes, a 25-horsepower motor is sufficient to raise the six-ton load.

East Vulcan Head Frame. This is a reinforced concrete structure of rectangular shape. While it is only thirty feet above ground, the structure really begins as a shaft lining thirty-five feet in the rock, and forty feet through hard pan and gravel, so that the total height of concrete is 105 feet. As the shaft was opened on a hillside, a haulage adit reaches the shaft at a depth of sixty feet below the surface and from there up the shaft was enlarged to about twenty feet square to give space for a skip dump, and the same dimensions were carried up to the head sheaves. The reinforcement was obtained from discarded wire ropes and the work was done by the mine force of shaft men.

West Vulcan C Shaft Head Frame. This building was finished in the summer of 1917, but much of it was done in the previous winter with temperatures extending to minus 20 degrees. The structure is sixty feet high from the sollar level to the center of the head sheaves. As the top of the shaft is a fill of waste rock, pierced by tunnels and cut into by an old Cornish pump "bob pit," the foundation of the head frame is a system of heavy girders and piers which contains about one-third of the total volume of the concrete. The structure is a simple system of reinforced columns, girders, beams, and floors, with a small bin projecting on one side and a steel stairway cantilevered out on the opposite side. The principal columns are 30″ x 30″ and a number of the girders are 15″ x 48″. The backstay columns lie approximately in the plane of the resultant of the rope pulls. Nearly all the reinforcement is discarded hoisting rope. The structure was built by the mine force of trestle men. This head frame is mentioned in an article on page 611 of Engineering and Mining Journal for 1917.

Angle Sheave Frames. At East Vulcan, West Vulcan and Curry there are angle sheave frames for carrying the hoisting ropes around angles in various planes. They are built of structural steel, reinforced concrete and structural steel, or all reinforced concrete. These structures are described, and the mathematics of the problems presented, in Engineering and Mining Journal issues of February 20 and 27, 1915.

Concrete Stack. A concrete draft stack at West Vulcan mine can claim notice only because it was built by the mine force.

The Loretto Mine. The Loretto mine, located at Loretto, Mich., and operated by the Loretto Iron Company, is the eastern-

most active property on the Menominee range. It was opened up in 1893 and has operated almost continuously to date. Output to January 1, 1920, is 2,400,000 tons.

The mine is located on the north formation, which at Loretto is about three-fourths mile north of the south formation on which the principal mines of the range are located. Developments at the mine seem to indicate that the duplication of the formation is due primarily to faulting and not to folding, as has been generally supposed.

Penn Iron Mining Co., Vulcan, Mich. Angle Sheave Stand, Curry Mine.

The first ore mined was taken from a small marginal fold in dolomite. This was a very high-grade low-phosphorus ore but bottomed at less than 200 feet in depth. The present mining is from several small ore bodies located on a small but complex drag fold on the main formation. The largest of these ore bodies averages about 950 feet long, from ten to forty feet in width, and is developed to a depth of 800 feet. The analysis of this ore body averages: Iron (natural), 51.00; Phosphorus, .065. The pitch of the ore bodies is to the east. The strike and dip are that of the formation: strike, almost east and west; dip, practically vertical. All of these ore bodies extend up to ledge and are covered with about twenty-five feet of overburden.

The Sturgeon River formerly flowed over the property, preventing the complete extraction of the ore, but it was diverted around the ore bodies in 1908.[1] The ore is at present mined by the top slicing method.[2]

The property is operated through two shafts in the foot wall: a hoisting shaft near the west end of the ore bodies, which is 900 feet deep, and a timber shaft near the east end which is 800 feet deep. The 700 and 800 foot levels are at present the main hoisting levels.

The mine is changing from steam to electric operation. At present all but the main hoist and compressor are electrically operated, and they will be changed as soon as the new equipment is delivered. Power is purchased from the Peninsula Power Company.

---

[1] "Diversion of the Sturgeon River at the Loretto Mine," by C. H. Baxter. Lake Superior Mining Institute Proceedings, Vol. XVI, pp. 168-170.

[2] "Method of Mining at the Loretto Mine," by C. H. Baxter. Lake Superior Mining Institute Proceedings, Vol. XXI, pp. 29-32.

Emmett and Breen Mines. Four miles east of Loretto, at Waucedah, are the Emmett and Breen mines, both of which were closed after producing a small tonnage of ore. It was at the Breen that the first discovery of ore was made on the range by Thomas and Bartley Breen in 1866, though active exploration did not begin until 1870.

East of Waucedah the iron bearing formation lies beneath the horizontal Cambrian sandstone and younger rocks.

General. The Menominee iron range has at the present time comparatively few active mines and the list of those not operating is long. Between the cities of Iron Mountain and Norway all the mines are inactive, as are also all of those east of Loretto. The visitor will naturally ask why, for it must be evident to him that the Menominee is the most favorably located of all the iron ranges of the Lake Superior district. It is simply because the ore on the Menominee range averages lower in iron than that of the other ranges, and only in a few places has there been any considerable concentration. It is impossible for the mines of the Menominee range, producing low grade ore, to compete with the open pit mines of the Mesabi, producing high grade ore. If the Menominee range were in Europe instead of in the United States it would be very active. Though it cannot enter present

competition to a very great extent, it must be considered a great national asset, for the high grade ores will last only a short time in the life of the nation and it will then be necessary to use those of lower grade. When that day comes the Menominee range will come to its own, for it will be able to produce cheaply a very large tonnage, and the area will be alive with activity.

Mining Methods. The following summary of mining methods on the Menominee range is based on the practise at several representative mines. The methods employed at the Chapin mine may be outlined as follows:

The Chapin mine lies on the south side of the most southern ledge that has been eroded to the dolomite in a smaller west pitching fold superimposed upon larger main folds. Folding has pushed the strata through an arc of greater than 90 degrees, so that the dolomite now lies upon the slate near whose base lies the iron bearing member. After tilting, the lean iron bearing formation has been concentrated by leaching by underground water more or less completely. Where this concentration has been complete, a soft, readily caving ore results; where incomplete, a harder, firmer and more closely bound together ore is more common. Alterations also took place in the neighboring formations; the slates in some places are soft and friable and in other places they are unaltered. The alteration of the slate has set up troublesome problems, whether they occur in the foot wall or in the hanging wall. The dolomite has also been altered materially, having furnished enough magnesium to form considerable talc between the dolomite and the iron bearing formation proper. This talc, when exposed, swells and a very serious mining problem results. The water bearing formation is the dolomite; the ore body itself is dry.

The selection of the shaft site under these peculiar conditions involves one of the ordinary mining problems, complicated by the number of separate ore bodies and the peculiar conditions as regards water. In the first place, each shaft must serve a number of separate ore bodies; for this reason it must be accessible to all of them. Due to the nature of the ore and the iron bearing formation, the shaft must be so located as to miss these strata. For these reasons, only shafts sunk in the hanging or foot wall are considered. The hanging wall shaft in general is not as satisfactory as the foot wall shaft, but in this region it has the advantage that it intercepts all of the water before it reaches the ore body. In this way the water may be pumped

without attempt to lead it across the ore, with the trouble which would result from such a procedure. Shafts are sunk through the surface quicksand by the freezing process. When trouble arises in the lower formations from talc seams or water courses, the shafts are concreted to guard against this.

The early mining method employed at this property was a form of back-stoping. Stulls were set upon the foot wall normal to the dip of the ore, the bearing upon the hanging wall being secured in some cases by means of headblocks. The objections to this system were that the ore body was usually too wide for the stulls which could be handled in the shafts, and that the ore slabbed off when left on the hanging wall, and that where the ore body was narrow and all of the ore was extracted the slate hanging wall crumbled away from the stulls and in this way brought about mixtures of gangue with the ore. Considerable danger to the miners also results from this condition. The next method tried was the square set room and pillar method. Rooms were opened up by means of the square set system and the ore extracted from them. Due to the heavy ground it was necessary to leave large pillars between successive rooms. The ore in these pillars was not firm enough to stand up under its own weight through the height necessary, and the crushing of the pillars caused considerable difficulty. This was of more importance when caving extended into the lower floors of the square set stopes which had been partially worked out. Later filling with waste was adopted, the waste being secured from drifts in the foot wall and from the surface. This method proved too expensive and was open to the same objections, that the pillars left between the filled stopes were too heavy, crushed under their own weight, and could not be completely extracted. By the time these methods had been tried out the peculiar nature of the ore was pretty well determined. The ore was soft; stopes could not be held open; when the ore was undercut it would cave readily, bringing down the surface. On account of these factors the present ore caving method was adopted. The shafts are sunk in the hanging wall or foot wall. The ore body is reached by cross cuts from the main shaft. Main level drifts, 100 feet apart vertically, are then driven the full length of the ore body. These drifts are driven generally in the center of the ore body, although in some instances a drift along the foot wall is used as a main level drift. When these drifts have been driven a sufficient distance, raises thirty-five feet to fifty feet

apart are run up to the level above. Sub-level drifts are then driven, half way between the two levels, connected to the raises by cross cuts to serve as a means of communication and passage. When the raise has been completed to the level above, cross cuts are started to both the foot and hanging walls at a point sixteen to eighteen feet below the upper level. These are continued to the foot and hanging walls. When they have been completed the development is finished and the extraction of the ore begins. Rooms are opened up one or two sets wide at right angles to the cross cuts and are continued in either direction to a point half way through the pillar. When these rooms are completed the ore over the first set is caved. In this manner, by mining out a room eight or nine feet wide and then caving in the remaining eight or nine feet over the room previously mined out, practically all of the ore is extracted. After this work has been carried back somewhat a new set of cross cuts sixteen to eighteen feet below the first ones are driven to develop the next sub-level. In this manner when the upper sub-level is worked out the development has been carried so far that mining upon the next lower sub-level may proceed without delay. This method has the advantage that no attempt is made to maintain any amount of open ground, no heavy pillars are left which later cannot be extracted and the timber cost and maintenance cost is very light.

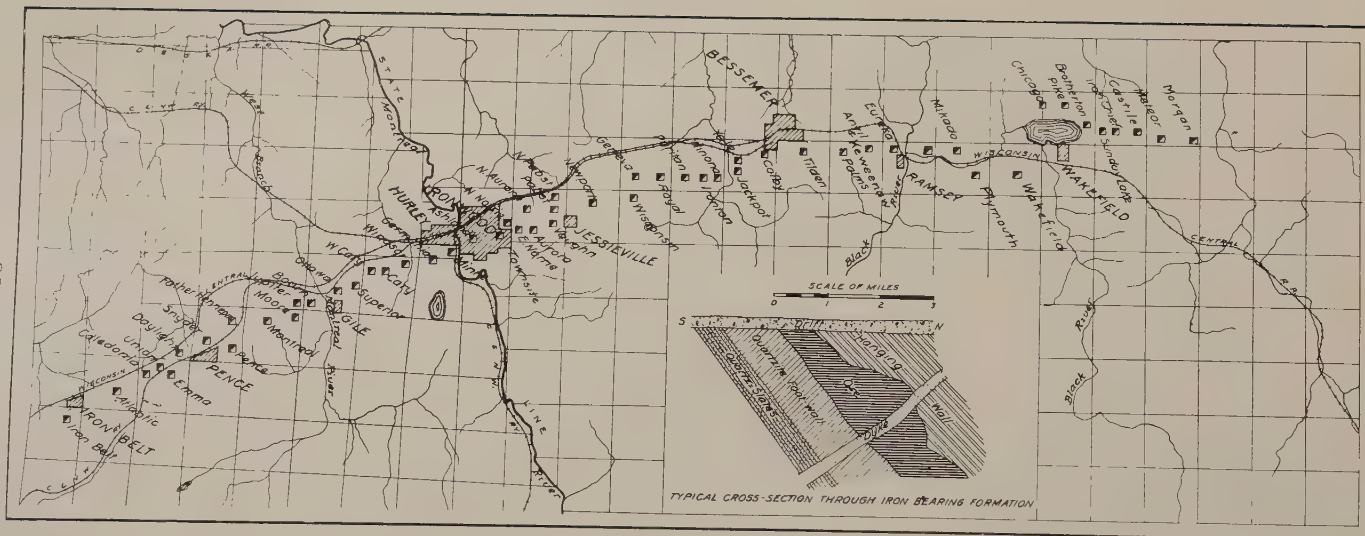
A modified square set room and pillar system has been followed in the Vulcan mine. In this method, after the shaft has been sunk, and a cross cut driven to the ore, an irregular development drift is driven throughout the center of the ore body. This is cross cut at intervals to the limits of the ore body. The square set layout is then fixed so that the alignment of sets may be properly taken care of when the initial sets in each successive room are put in. In this case the levels are again ordinarily 100 feet apart. The development is arranged to provide for rooms three sets wide, separated by pillars of the same width. These square set rooms are now worked to the full distance across the ore body, and from the level floor up to the point about fifteen feet below the level above, leaving a fifteen-foot level below. In some cases the pillar below this level is omitted. After that mining proceeds. The sides of the pillars are closely lagged and when the square set room has been completely mined out, it is filled. In mining the upper floor of these square set rooms the dirt falls upon lagging which is arranged much in the manner of ordinary wagon dump boards, and is dropped from the lagging

into chutes below, from which it is drawn into the mine cars. To secure the filling necessary drifts are driven in the foot and hanging walls, mine waste is used, and material is brought down from the surface. No timber is recovered.

When the ground has thrown no weight the pillar is extracted by means of top slicing or its side sliced by taking one set from one stope, then one from the other, and finally the center one is removed. When evidence of considerable weight is shown, slicing or ore caving is employed. In some instances pillars have been mined out after stopes have been completely filled in the same manner as were the original square set rooms.

In the Pewabic mine block caving has been used almost exclusively. The formation is 250 feet wide and it stands inclined at an angle of 90 degrees from the horizontal. The foot wall is gray Traders slate, the hanging wall Red Briar slate and both are uniform in strike and dip. The development is carried out as follows: Cross cuts run from the shaft to the foot wall and across the ore body. Foot and hanging wall drifts the full length of the block to be caved are run just inside the folds. These are connected by cross cuts spaced thirty feet center to center, and these again are crossed by drifts which parallel the main drift and which are spaced thirty feet center to center. In this manner the block is resting upon solid pillars twenty-two feet square, approximately. Shrinkage stopes are now put up above the drift on the foot wall side, and the end cross cuts of the block, to a point within six feet of the level above, leaving this small level pillar to support the upper level or the caved material as the case may be. When these stopes are completed these small level pillars are blasted out and a block 250 feet square, approximately, is left completely cut away on each end and along the foot wall.

Meantime a main haulage drift with cross cuts spaced fifty feet center to center has been driven in the slate wall about forty feet from the ore. Now the small twenty-two-foot pillars are weakened by drilling and blasting. When they have been blasted out the block will have dropped eight feet, and it is broken finely enough, due to crushing by its own weight, and can be loaded into cars. Now through this broken ore cross cuts are poled from those started from the main haulage way in the slate wall through to the hanging wall. Drifts are turned at right angles to these cross cuts and poled into the ore. A sufficient number of these drifts are started so that the shoveling, which may now begin, will draw the entire block at a uniform rate until all of the ore



Map showing location of mines on the Gogebic Range.

has been extracted. The recovery under this system is relatively high.

The Tobin mine uses a block caving system similar in the main to the one just described; but with the exception that the levels are 125 feet apart, and that a level twenty-five feet above the main level is driven and that caving takes place above this point. In this system twenty-five foot level pillars are left, through which raises, which later serve as chutes, have been driven twenty-four feet apart on the cross cuts across the ore body and fifteen feet apart along the line of the drifts which parallel the main drifts. When the block above the sub-level is caved the ore is drawn through these chutes until it is completely extracted. The level pillar above each level is drawn with the block just below the level, when it is mined. The advantages of this modification lie in the saving in labor which results from the drawing of the ore through chutes rather than shoveling.

Among other mines, the Baltic uses an ore caving system; the Bates, shrinkage stoping; the Caspian and Davidson, top-slicing; the Chatham and the Amasa Porter, an ore caving system.

These descriptions make no pretense of being complete in detail, but merely are given to bring out some points of difference in the mining practice as it obtains on the Menominee range. The same descriptions may be applied in general to similar work on the Marquette and Gogebic ranges.

THE GOGEBIC IRON DISTRICT

Location. The iron formation of the Gogebic district (including the Penokee) comprises a narrow belt south of the western part of Lake Superior extending from Michigan for a considerable distance into Wisconsin. From the mouth of the Montreal River (about twenty-five miles west of Ashland) the iron formation is only about twelve miles distant, but it is about twenty miles south of Ashland. Beginning on the east at a point about eight miles east of Wakefield, Mich., it extends through Sunday Lake, Bessemer and Ironwood in Michigan, and thence south of west through Hurley, Wis., and only a short distance south of Mellen, Wis. About eight miles westward from Mellen, the formation disappears, but six miles further west it is known to reappear and continue thence for about eight miles. The total length of the range is about sixty miles, two-thirds of this distance being in the State of Wisconsin; but nearly

Open-pit of Colby Mine near Bessemer, Mich., where ore was first discovered on the Gogebic range.

Richard Langford, the original discoverer of ore on the Gogebic Range.

ıll of the ore has been obtained from the eastern third of the listrict, which is in the State of Michigan.

History. This iron range was first noted in 1848 by Dr. Randall, assistant geologist to Dr. David Dale Owen, while fol-owing the fourth principal meridian northward. It was also reported by Charles Whittlesey in an account of a survey made n 1849, and published by Owen in 1852. Analyses of the iron ore are given with the following account. "The bed of magnetic ron ore south of Lac des Anglais is of extraordinary thickness, 25 to 60 feet. * * * In the wild and deep ravines where the Bad River breaks through the range, there is a cliff of slaty ore * * * probably three hundred feet thick. * * * I estimate more than one-half of this face to be ore, and in places the beds are from ten to twelve feet in thickness, with very little inter-mixture of quartz * * * . The position of the best exposures of ore which I saw is such as to require from eighteen to twenty-eight miles of transportation to reach the lake."

Whittlesey prepared a geological map of the district in 1860, on which the crest of the range and the outcrops of iron ore are marked with wonderful accuracy. In 1858, Edward Daniels, of the State Geological Commission, mentions the dis-trict as follows: "The mineral resources also promise richly. The most important of these are the great deposits of iron ore found in the Penokee Mountains. * * * The ore is princi-pally the magnetic and brown oxide, with traces of specular iron, and occurs in seams parallel with the stratification, varying from a mere line to fifty feet in thickness; it is of good quality, well located for quarrying, and practically inexhaustible."

Dr. I. A. Lapham, afterward state geologist of Wisconsin, published a brief account of the district in 1860, in which he states: "It will be seen that we have already discovered the ore in such quantity as to be practically inexhaustible, situated at points accessible to water power, and having bold fronts, ren-dering it comparatively easy to be quarried."

R. Pumpelly and T. B. Brooks published a brief description of the district in the report of the Michigan Geological Survey for 1872, accompanied by a map showing the position of the iron bearing rocks in a general way.

Again in Volume III of the Geology of Wisconsin, published in 1880, there is a detailed account of the geology of the Penokie range by R. D. Irving.

The first successful mining explorations on the Gogebic range were conducted by F. H. Brotherton in 1879, with results which were remarkably accurate, but the first discovery of soft ore in place and in large quantity was probably made during the following year by Richard Langford, who reported it to N. D. Moore. Explorations in June, 1881, for the Cambria Iron and Steel Company, resulted in discoveries on land now known as the Colby mine. Actual mining was begun here in October, 1884, the first ore being shipped on six flat cars to Milwaukee and thence to Erie. The Sunday Lake mines were discovered by George A. Fay in 1881 and 1882. During the latter year the great Norrie mine was first discovered. These discoveries were followed by a very rapid development, and the shipment of large tonnages resulted in a wave of mining stock speculation during 1885-87 which led to the formation of mining companies in this district with a nominal capital exceeding one billion dollars. The boom collapsed in the latter part of 1887 and many companies disappeared, but the production of ore steadily increased until 1890, when industrial depression caused a falling off for a few years.

The Duluth, South Shore and Atlantic Railway had been built nearly parallel with this iron district before exploration began, and this fact contributed to its rapid development. The Wisconsin Central crossed the range at Penokee Gap in 1873, connecting the district with Ashland, and in 1887 built a branch line to the center of the district. A line which is now part of the Northwestern was built from the mines direct to Ashland in 1885.

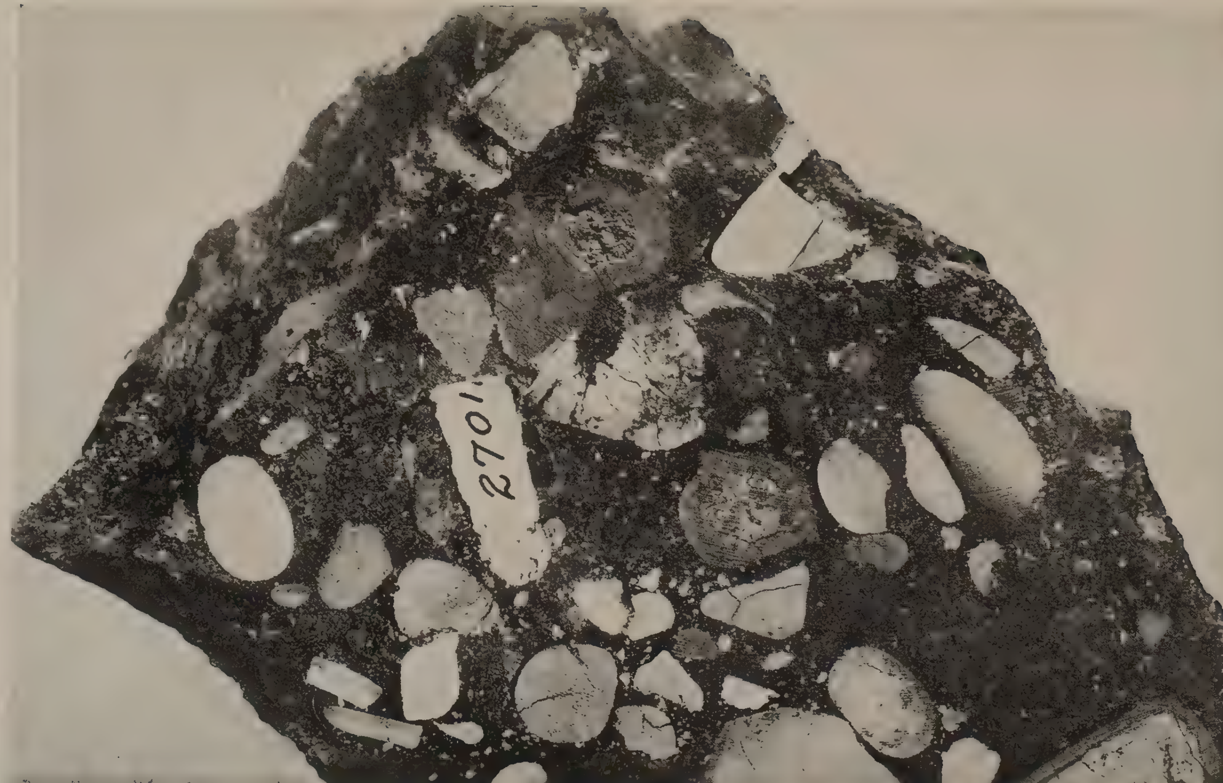
Production. The first production of iron ore from the Gogebic district amounted to a little more than one thousand tons, and was sent from the Colby mine to Marquette in 1884. In the following year the shipments amounted to more than one hundred thousand tons, which were increased to three-quarters of a million tons in 1886, one and a half million tons in 1888, and nearly three millions in 1890. During the next few years shipments fell off, owing to the period of commercial depression which affected the whole Lake Superior district, but for the whole decade of the nineties the Gogebic range produced nearly as much as the other iron ranges of Michigan, standing first in 1892 and 1895. During the next decade the shipments from this district were somewhat less than from the other Michigan districts, but within the last decade (1910-1919) the Gogebic range has taken first rank in the state.

Geology. The geological succession in the Gogebic district was described as consisting of Upper and Lower Huronian sediments resting unconformably upon Laurentian granites and Keewatin schists, and unconformably below Keweenawan igneous rocks with some sediments, by Van Hise and Leith in the Lake Superior Monograph, published in 1911. Four years later R. C. Allen, state geologist of Michigan, discovered evidence which he regarded as demonstrating the existence of three divisions of the Huronian in the district, which would then correspond in this respect with the threefold division previously recognized in the Marquette district. The relation of this classification to that given in the monograph is shown in the following table:

Geological Succession in the Gogebic District

Van Hise-Leith, 1911.			R. C. Allen, 1915.
	Copps formation (Allen)	Graywacke and slate Ferrug. and cherty slate Conglomerate	Upper Huronian
Upper Huronian (Animikie)	Tyler slate Ironwood formation Palms formation		Middle Huronian
Lower Huronian	Bad River limestone Sunday quartzite		Lower Huronian

The complete account of the geology of the Gogebic district has not yet been written, and it is considered probable by certain geologists that more than three divisions must finally be recognized in the Huronian of this district, and perhaps elsewhere. More detailed stratigraphy of the Gogebic area is furnished by W. O. Hotchkiss, state geologist of Wisconsin, in an article published in 1919 in the Engineering and Mining Journal, in which he subdivides the lower portions of the Tyler formation and the Ironwood iron bearing formation as shown in the following table:



Polished specimen of leached conglomerate from Pabst member in the Plumer mine, Gogebic Range, cut parallel to beds. From W. O. Hotchkiss, Geology of the Gogebic Range, Eng. Min. Jour., Vol. 108, 1919.

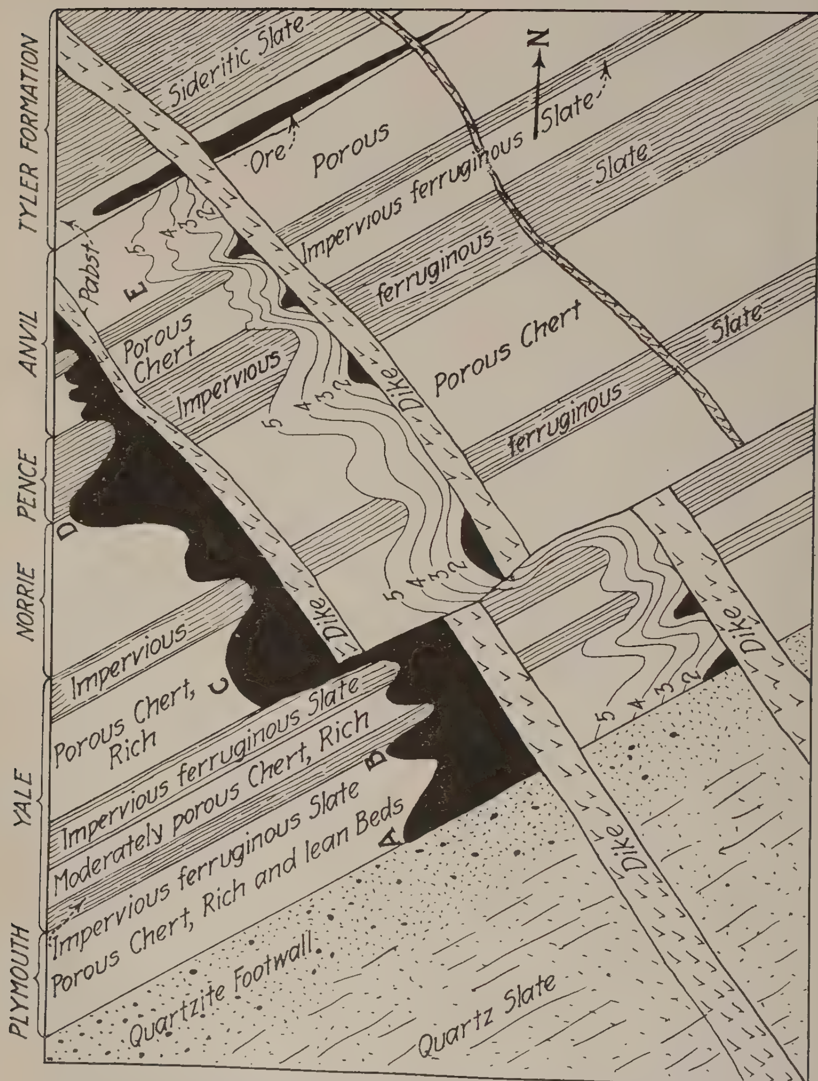
Subdivisions of the Tyler and Ironwood Formations

Tyler formation	Graywacke slates Iron carbonate slates Pabst member, cherty ferruginous slates
Upper Ironwood formation	Anvil ferruginous chert member Pence ferruginous slate member
Lower Ironwood formation	Norrie ferruginous chert member Yale member, interbedded ferruginous cherts and slates Plymouth ferruginous chert member

The structure of the Gogebic district is very simple in its major outlines. The Huronian sediments have a strike which is almost parallel with the line of outcrop of the iron bearing formation, and a dip which is rather steep to the north. In some places the iron formation forms the crest of a ridge extending for miles, but elsewhere the underlying quartzite, or even the granite beneath, occupies the crest of the ridge formed by the iron formation. A second parallel ridge is composed of Keweenawan igneous rocks. The chief watercourses cut almost directly across these ridges, forming notches or gaps, as illustrated notably in Penokee Gap. The elevation of the area varies from 800 to 1,200 feet above that of Lake Superior.

In the eastern end of the district these east-west beds have suffered very important faulting, which has only recently been fully understood. In addition to the major Sunday Lake fault, which offsets the whole formation about a mile, there are many other faults of varying strike and dip, a few of which have been worked out in connection with the search for ore, as may be illustrated in the diagrams by Hotchkiss.

Ores. The iron ore is estimated to form about 1 per cent of area of the iron formation, but extends to great depths, a very large ore body being known at a depth of 2,500 feet. In both the east and west ends of the district the character of the formation has been modified by intrusive igneous rocks so that the ore has been converted more or less completely into magnetite. In this condition it has not been concentrated by later leaching as rapidly as in the unmodified state. The average dip of the Ironwood formation in which the ores occur is toward the

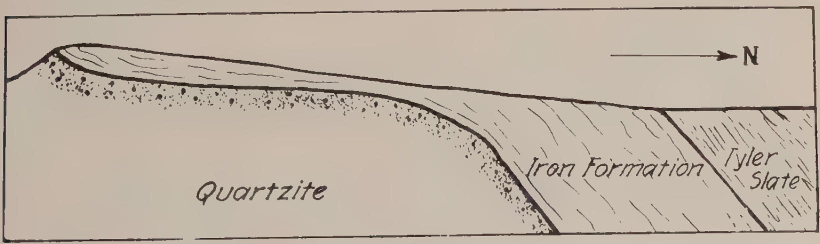


Cross section showing final form (an upper dike) and various stages (on second dike) of an ore body extending from foot to hanging wall, on the Gogebic Range—Black is ore from W. O. Hotchkiss: Geology of the Gogebic Range, Eng. Min. Jour., Vol. 108, 1919.

north at an angle of about 65°. The foot wall of the formation is formed by quartzite and the hanging wall by the Tyler slate. Numerous greenstone dikes of Keweenawan age cut through the entire Huronian series in such a way that the intersection of the dikes with the bedding planes usually pitches to the east. These intersections, where the underlying sediments are impervious, form eastward pitching troughs at angles varying from fifteen to thirty degrees, in which most of the ore is found. In some cases the ore beds follow the foot walls almost exclusively, but recent work has shown that they occur also near the hanging wall, or at least in the hanging wall portion of the iron formation. The ores are associated with brecciation, fissuring, or faulting, more or less independently of their association with the troughs. There are fault planes both parallel with and intersecting the bedding, with displacements in various directions. The ore in some places lies between the displaced edges of dikes. Still another factor influencing the location of ore deposits is the irregular distribution of the iron in the original sediments. It is natural that the best ore bodies are found closely associated with the richer original beds.

At both ends of the district the iron ore has been converted largely into magnetite with the production of coarse quartz, amphibole and other silicates. In this condition the iron formation has suffered very little secondary concentration, and material rich enough in iron for exploitation by ordinary methods is rare or entirely absent. However, such ores are amenable to magnetic concentration, and it is probable that the magnetite will be recovered in this way.

The secondary alteration of the iron formation is accomplished by waters following pitching troughs, such as already mentioned, or by following fissures or bedding planes independent of the dikes.



Sec. 18-44-3W.

Cross section of fold in section 18, T. 44 N., R. 3 W., on the Gogebic Range, showing the quartzite, the iron formation and the Tyler slate. From W. O. Hotchkiss.

Originally, the iron bearing formations consisted largely of cherty iron carbonate interbedded with ferruginous slates and cherts. The alteration of this material into ore was accomplished by oxidation and hydration of the iron minerals in place, the removal of silica in solution, and the transfer of iron oxide and iron carbonate from certain parts of the formation to other portions where the ores were concentrated. The oxidation and hydration of the iron minerals usually occurred long before the other changes. The concentration of the chief ores was well advanced before Upper Cambrian time, but has continued more or less irregularly to the present time.

Mining Methods. There are several methods of mining in vogue on the Gogebic range, a few of which will be mentioned. Inclines are usually sunk in the foot wall, although some vertical shafts are in operation.

Cross cuts are driven to the ore body, and main level drifts are driven along the side of the ore body. Opposite the shaft a pillar is left, approximately 250 feet long, along the ore body. It extends clear through to the hanging wall. At each side of the pillar cross cuts are driven to the hanging wall and additional cross cuts are driven, spaced approximately 125 feet, center to center. Drifts parallel to the main drift are driven at the same interval, blocking the main level out into square blocks 125 feet on each side. Raises are now driven to the top of the ore or to the level above. These raises are driven at the intersections of the drifts and cross cuts above described.

When this work has been completed, the sublevel just below the top of the ore is developed. This subhead is started fifteen to eighteen feet below the top and blocked out by drifts and cross cuts parallel to and directly above the ones on the main level. A second set of drifts and cross cuts is driven, which subdivides the pillars again into blocks approximately sixty feet square.

Stoping then begins, and is carried on as described in the discussion of ore caving for the Menominee range. Development for successive sublevels is started, so that no break will occur in regular mining operations when the upper cuts are worked out.

In the narrower parts of the ore body, shrinkage stoping is employed. Raises driven on fifteen feet centers are put up to the level above. A level pillar is left above each level, and sufficient ore is drawn during development to allow sufficient room

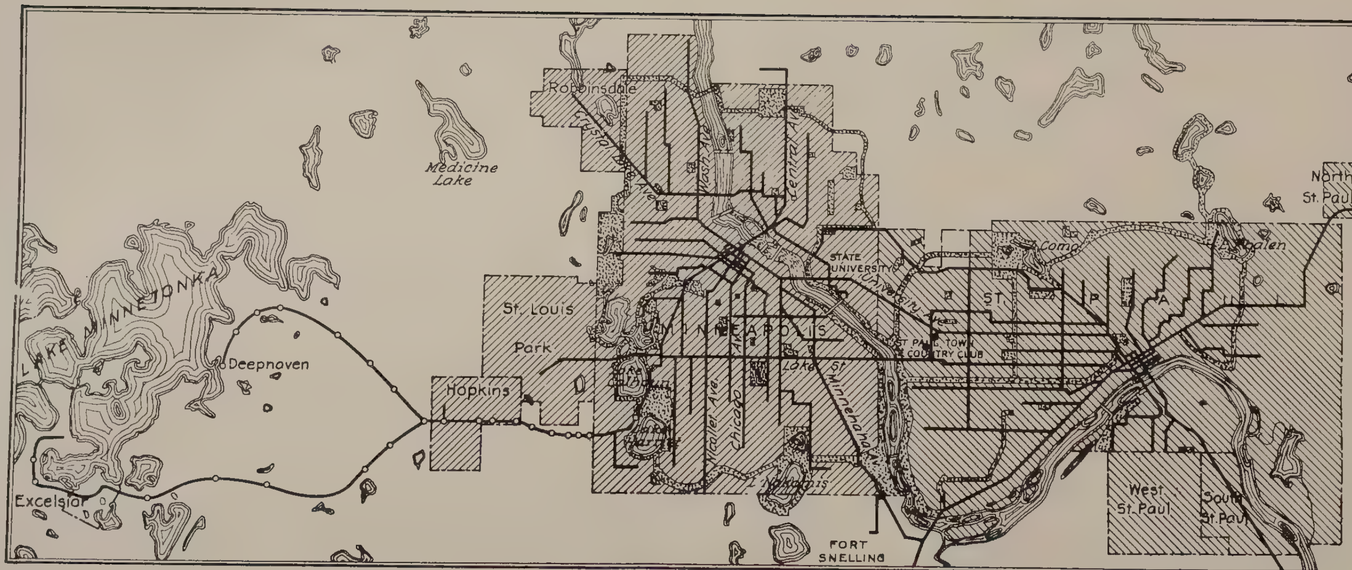
for miners to work. When the work has been carried up to a point about fifteen feet below the upper level, the ground remaining as a pillar below the upper level is drilled. When it is blasted, it falls onto the broken ore, bringing down the pillar left just above the upper level.

Where the ore bodies are hard, underhand stoping is employed.

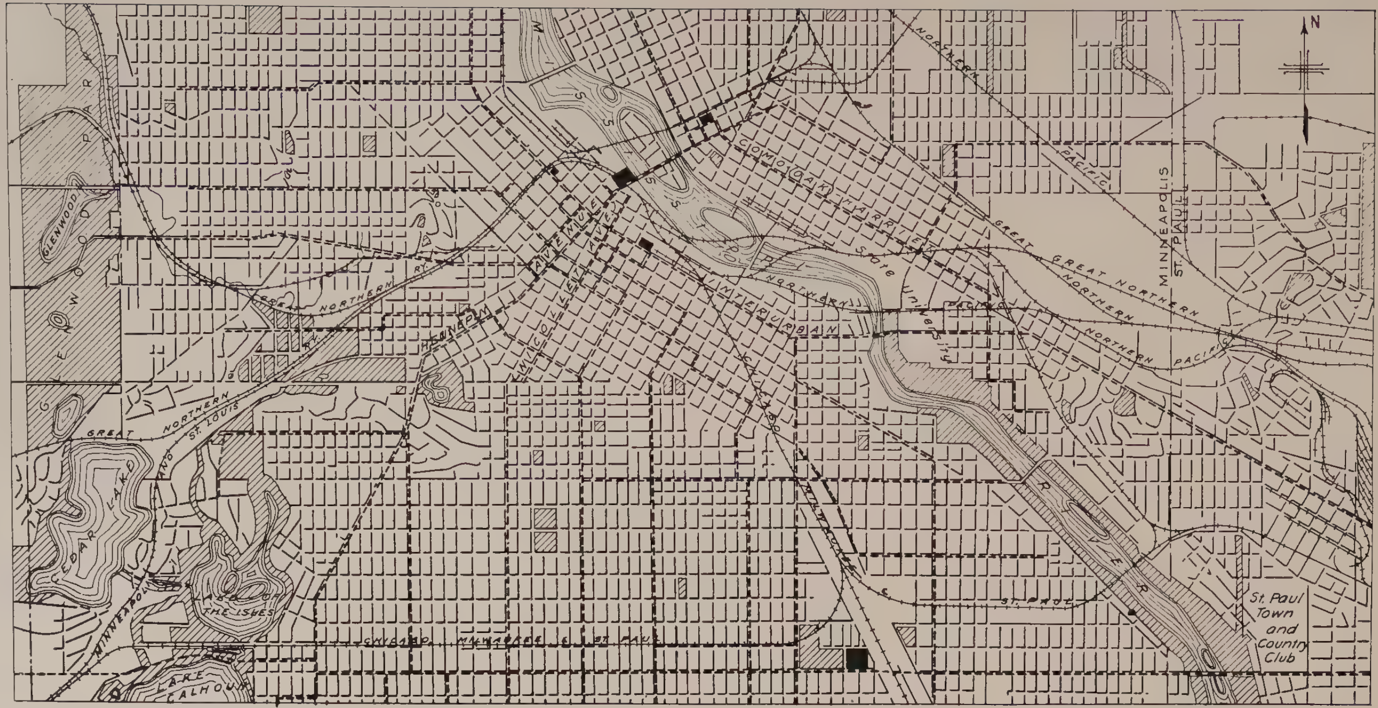
A combination of ore caving and shrinkage stoping has been resorted to on the Gogebic range. The development is as noted for ore caving, with the single exception that the bottom sub-levels are mined first. The result is a series of step-like blocks of ore, the one above a given sublevel extending out over the stope by ten to fifteen feet. This arrangement is followed from level pillar to level pillar. The level pillars are developed for shrink stoping. This system has the advantages of shrink stoping, and, moreover, at all times the work is being done under the cover of the projecting block overhead. This system, of course, would not work in the soft ores, but in the hard ores it is economical, the extraction is nearly complete, and it is safe.

THE TWIN CITIES

The cities of St. Paul and Minneapolis are located side by side on a double loop in the Mississippi River near the eastern boundary of Minnesota. Both cities lie on both sides of the Mississippi River, which in this region describes an S-shaped curve. The two cities together have a population of over 600,000 people, gathered in an area which has grown to be a single urban district inasmuch as the two cities have expanded until they occupy all the territory formerly between them, though the business centers are ten miles apart. St. Paul is located at the head of navigation on the Mississippi River and Minneapolis, farther upstream, at the Falls of St. Anthony. A recent water-power development below the Falls of St. Anthony, constructed by the Federal Government, has at the same time made possible navigation to the foot of St. Anthony Falls through a lock around the dam which replaces the former rapids. Minneapolis, in 1920, had a population of 380,000 people, and St. Paul, 235,000. The two cities occupy land at an elevation of 700 to 900 feet above sea level. The average elevation is slightly less at St. Paul. Minneapolis has nearly 4,000 acres of parks and parkways, while St. Paul has nearly 2,000. The Twin Cities have



Map of St. Paul, Minneapolis and environs, showing relations of two cities and parkways.

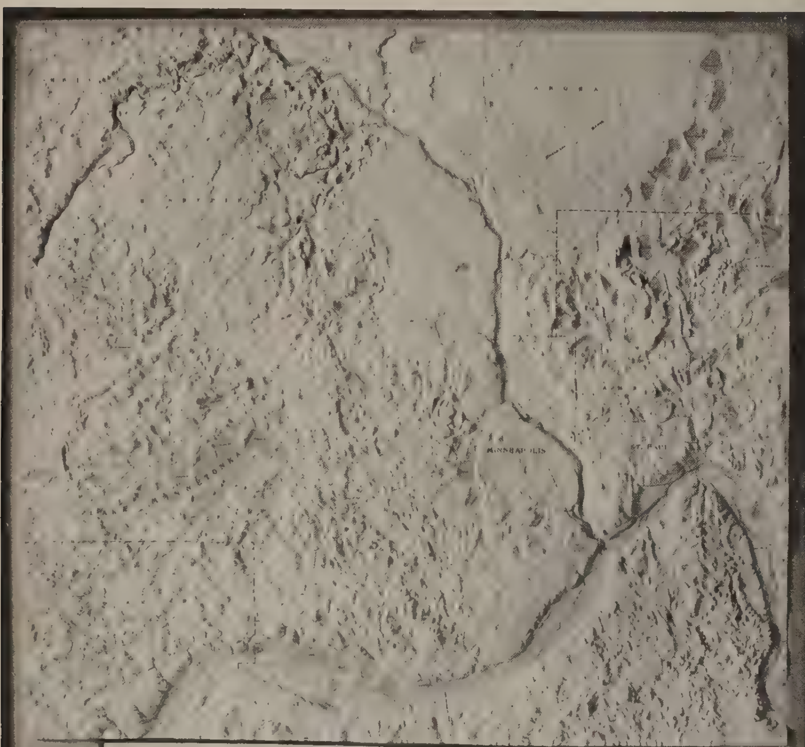


Map of central portion of Minneapolis, showing chief street car lines, parks, State University and Town and Country Club.

one of the best systems of electric street railways in the country, with nearly 400 miles of track and frequent and rapid service. Within the city of Minneapolis there are sixteen bridges over the Mississippi River, some of them being quite unique. Thus, the Great Northern Railroad Company constructed, some twenty years ago, a stone arch bridge over the river, 2,400 feet long, and showing a compound curve in its plan.

In 1911, a modern steam turbine reserve station was built below the falls at Minneapolis. Recently this station has been enlarged to 70,000 h.p. The natural waterpower furnished by St. Anthony Falls has made Minneapolis the headquarters of the flour milling business in this country. A large part of the wheat grown in the northwest comes to Minneapolis to be ground into flour.

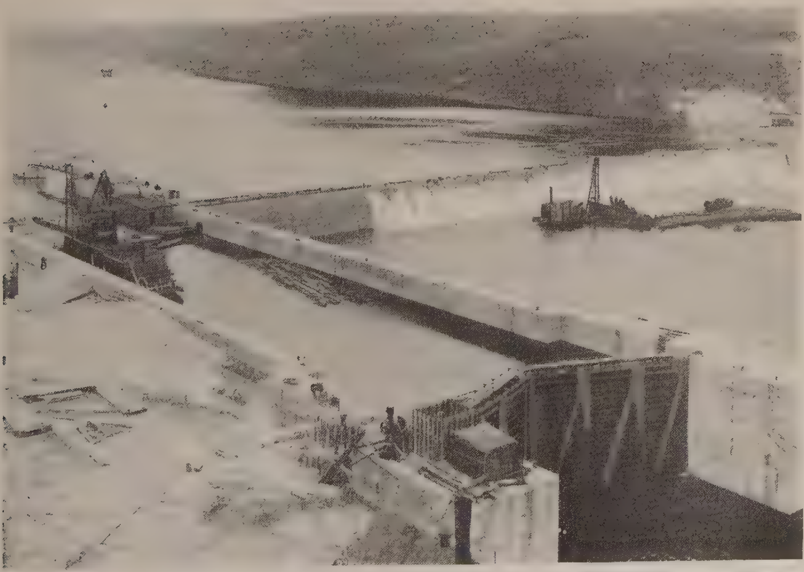
The water supply of the city of Minneapolis is taken from the Mississippi River at the upper limits of the city. It is pumped through a steel force main a distance of three miles to the Colum-



RELIEF MAP OF MINNEAPOLIS, ST. PAUL AND ENVIRONS

According to the latest data of the U. S. Geological Survey, War Department, Railroad and Street Railway Maps

Third Avenue Bridge, Minneapolis.

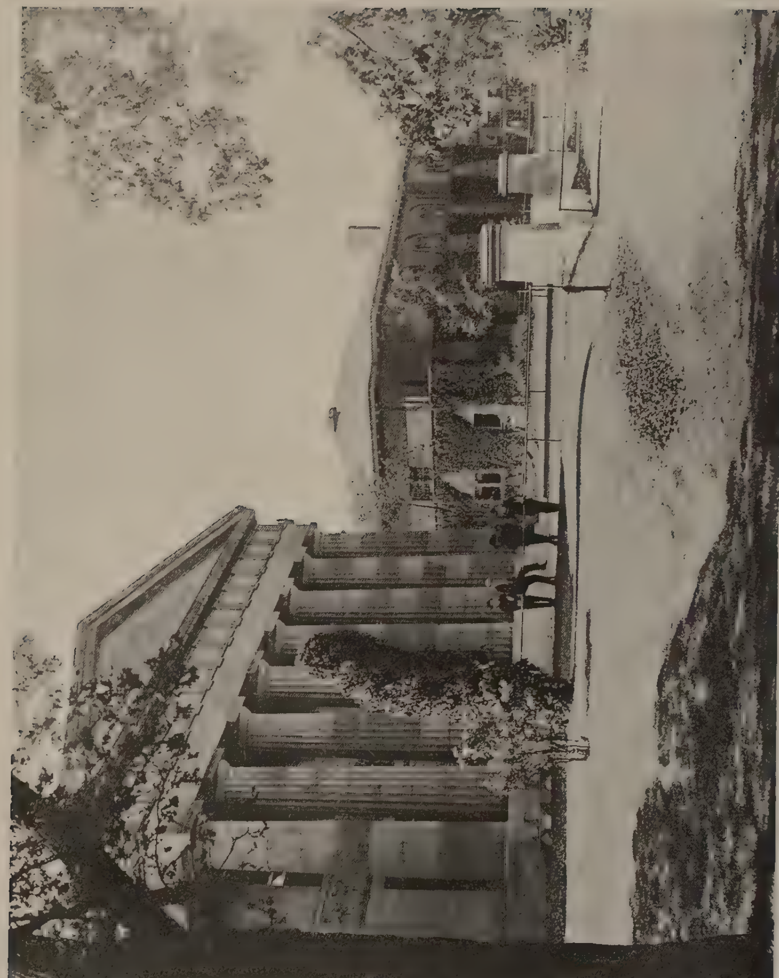


First Boat through the locks at Minneapolis.

Minnehaha Falls, Minneapolis.

Town and Country Club, St. Paul.

Minnesota State Capitol, St. Paul.



Campus, University of Minnesota, Minneapolis

Historical Round Tower, Fort Snelling, Minn.

Art Institute of Minneapolis.

bia Heights reservoir. It is here passed through a mechanical filtration system, consisting of twenty-four filters, with a capacity of about eighty million gallons of filtered water daily. The pumping station contains a Worthington electrically driven centrifugal pump operating at 72 per cent efficiency under a head of 250 feet, with a capacity of twenty million gallons per day; a De Laval centrifugal pump, electrically operated and giving more than 80 per cent efficiency under the same head, with a capacity of thirty million gallons per day, and two triple-expansion Holly engines of fifteen million gallons capacity per day.

Within the last decade, three miles of track of the Chicago, Milwaukee and St. Paul Railroad have been depressed through the residence district of the city, and the cut has been spanned by thirty-seven reinforced concrete bridges of the slab-and-girder type.

The University of Minnesota is located in Minneapolis, with its Agricultural College about a mile away within the limits of St. Paul. Affiliated with its College of Engineering is a School of Mines, a State Geological Survey and a State Highway Department. A new mining laboratory is under consideration.

The Minneapolis Steel and Machinery Company manufactures in this city all sorts of structural parts in steel for mining, milling and smelting projects. This company has built large plants for such purposes, including the concentrator of the Moctezuma Copper Company at Nacozari, Mexico; some of the shaft houses for iron mining at Hibbing and elsewhere on the iron ranges; the plant of the Minnesota and Ontario Power Com-

Longyear Diamond Drill exploring copper lodes, Keweenaw Peninsula, Michigan.

pany at International Falls, Minn.; the shops of the Soo Line Railroad; the concentrator of the Utah Copper Company at Garfield, Utah, and many other similar structures in all parts of the country.

The E. J. Longyear Company has its headquarters at Minneapolis and its manufacturing shops at Marquette, Mich. It does an extensive business in diamond drilling as a means of prospecting for ores of all kinds, and has had extensive experience in such work on the iron and copper ranges of Lake Superior, and more recently a wider experience in all parts of this country and in some foreign countries.

Longyear Diamond Drill Testing Bridge Piers at Sault Ste. Marie, Michigan.

THE CUYUNA IRON DISTRICT

Location. The Cuyuna iron district extends from the region of Kimberly, near the Center of Aitkin County, Minnesota, southwestward through Deerwood, Ironton, and Brainerd, across Crow Wing and Todd counties, across the Mississippi River, and for an unknown distance farther southwest in the same direction. It is known that the Huronian rocks, in which the ores of the Cuyuna district are found, reappear near the western border of Minnesota, but no ores have been found in this region. The district has a length of more than sixty miles, but the more important portion as now known is confined to Crow Wing County in an area which is less than thirty miles in its longest dimension. The commercial headquarters for the district are in the city of Brainerd, on the Mississippi River.

History. The discovery of iron ore in the Cuyuna district was accomplished with no aid from surface outcrops, but solely through the use of the dip needle. The mantle of glacial drift overlying the iron formation varies from twenty-five to 350 feet in thickness, and it was by means of the magnetic attraction of the iron bearing rocks that their presence was discovered with the dip needle by Cuyler Adams, about 1895. The general geologic map of Minnesota, published by the State Geological Survey in 1909, showed the extension of the Huronian rocks of the Mesabi district passing through this area. Two years later, Leith published a sketch showing the hypothetic extension of the iron bearing formation through the same area. The first drilling was done in 1903, near Deerwood, Minn., by Cuyler Adams, and exploration was continued to the present time in increasing amount. The Northern Pacific Railway extends throughout the length of the district and affords an easy outlet for the ores. The Soo Line Railway completed a spur into the district in 1910. Both roads carry the ore to the docks at Superior, Wis., the average haul being about ninety miles. Shipments began in 1911, the Kennedy mine being the first producer. By 1918, the number of shippers reached twenty-seven, with a total output of nearly two and one-half million tons for that year.

Geology. The geological succession in the Cuyuna district is not known in detail, but the economically important formation is correlated by Leith[1] with the Virginia slate of the Upper

[1] Econ. Geol., vol. 2, 1907, p. 145. N. H. Winchell (Bull. Minn. Acad. Sc., vol. 5, 1911), regarded the Cuyuna ores as Keewatin like the ores of the Vermilion district.

Map of Cuyuna iron district, Minnesota, showing location of chief mines, railroads, shafts, and open pits.

Huronian or Animikie, within which is found the Deerwood iron bearing member, consisting principally of iron carbonate, where unaltered, but largely altered to amphibole-magnetite rocks, ferruginous slate and chert, and iron ore. The ores are in nearly vertical lenses from a few inches to 125 feet or more in width on the south range, and up to 500 feet in width on the north range. The greatest depth known on the north range is 1,000 feet, with an average depth of about 300 feet. The greatest depth known on the south range is about 250 feet, with an average depth of 150 feet, but the higher grade ores are found in this case in the upper hundred feet. Dikes and irregular masses of basic intrusive rocks are associated with almost every ore deposit known. These dikes may form one wall of the ore body or be separated from it by amphibole-magnetite rocks. The ore itself is sometimes highly magnetic, but at other times it may be half a mile from the line of greatest magnetic attraction.

The Cuyuna ores are of two types, hard and soft. The soft ores are black, brown or reddish hematite, similar to the soft ores of the Gogebic district. Some of these ores contain 55 to 63 per cent iron, others carry about 45 to 50 per cent. The hard ore is black or very dark brown hydrated hematite, carrying 50 to 60 per cent iron ore, or hard blue hematite containing 58 to 63 per cent iron. This latter type occurs in layers in the softer ores and is found more frequently close to intrusive rocks. These ores are nearly all non-Bessemer, only one mine shipping any Bessemer ore. The average iron content in the dried ore is about 56 per cent; the moisture averages about 10 per cent.

In addition to these variations, the district produces not only ordinary iron ore, but also manganiferous iron ore. In this respect it is peculiar in this country and of great importance, since it contains the greatest reserve of such ores known in the United States. The first shipment of manganiferous ores was in 1913, and five years later the shipment of these ores amounted to nearly a million tons. There are now three large open pits of manganiferous ores that are capable of producing a greater tonnage annually than the eighteen shippers did in 1918. These ores rarely have a manganiferous content in excess of 20 per cent. Some of them are high in phosphorus and low in silica; others are low in phosphorus and high in silica.

The Cuyuna ore deposits are quite irregular in shape. In many cases they are rudely lenticular, and the lenses are steeply inclined and pinch at both ends at distances of less than one mile.

Plan and vertical section of Ore Deposit on Cuyuna Range.

As the rock formations are very closely folded, many parallel lenses exist. Where the folding is open, the deposits may be almost flat. Mining has not yet been conducted beyond depths of 300 feet in ore, but drilling in several widely separated tracts has shown ore to a depth of at least 1,000 feet.

Beneficiation by washing the ore has been tried at different mines, but has never been required to any great extent. At one mine an elaborate washing plant was erected, but was not used for any great length of time. A simpler plant was used at another mine for several years, until ore was milled in the pit. Beneficiating the manganiferous ores has not been accomplished commercially. In most of the Cuyuna ores, the high silica content is due largely to chemically combined rather than mechanically intermingled silica.

Mining Methods. Some important mines in the district have been operated by stripping and excavating by steam shovel methods in open pits; and others, still undeveloped, will probably be exploited in the same way, but underground mining is the prevailing method in the district.

An innovation in stripping iron ore property consists in the use of hydraulic equipment to wash away the sand and gravel, which has proved to be quite economical, though a steam shovel is required for final clean-up work on top of the ore body. The over-burden is prevailingly sand or fine gravel, with a thin substratum of clay on top of the solid rock. Hydraulic methods can

Kennedy Mine of Rogers-Brown Ore Co. This was the first producer of the district and is now the deepest mine in the district.

Washing plant at the Rowe Mine, on Little Rabbit Lake.

Pennington pit of the Todd-Stambaugh Company. Head-frame of Armour No. 1 Mine of Inland Steel Co. in upper right-hand corner. This was the first open pit mine in the District.

be used wherever the topography is suitable, because water is very abundant. The stripping has ranged from twenty-five to eighty feet in depth. The shape and size of the ore deposits make the open pits long and narrow. The largest pit at present is three-quarters of a mile long and 800 feet wide from crest to crest.

The underground mines are opened by shafts which have been ordinarily of two types, one circular, lined with concrete, and the other rectangular lath- and drop-shafts. The deepest wooden lath-shaft is eighty feet. The deepest wooden drop-shaft is 125 feet, which is also the maximum depth reached by concrete shafts. The deepest working level is now at 360 feet. Underground mining is almost wholly by the slice and cave system.

Electric power is used on almost all the mines and for all purposes. Electric haulage is used on the main levels and on stock piles. Electrically driven centrifugal pumps are the prevailing type. Steam is kept ready for emergency use, and duplex compound Cameron pumps are employed. The quantities of water pumped are small, most of the larger mines pumping less than 1,000 gallons per minute, and very few ever exceeding 2,000 gallons. The electric current used is obtained from a privately operated central plant, where current is developed from water-power.

Hydraulic stripping at the Hillcrest Mine. Shows the sandy overburden and the equipment used. Boulders in the foreground have been washed down.

IRON ORE CONCENTRATION ON THE WESTERN MESABI RANGE*

The wash ore area on the Mesabi iron range covers a region of the iron bearing formation extending from Grand Rapids on the west to the Hibbing district, about forty miles eastward. Not all of the developed ore bodies are of wash structure; some are of such grades that they can be shipped direct as merchantable ore. It is safe to say, however, that 65 per cent of the ore is of a possible wash structure and of too high a silica content to be classified as merchantable ore. The increase in the number of washing plants completed each year on the western Mesabi shows that the product must be of a structure desirable for furnace operation. The following is a list of plants which were in operation, under construction, or with plans completed, at the end of 1918:

Iron Ore Washing Plants on Mesabi Range

Plant	No. of Units	Plant	No. of Units
Trout Lake	6	Harrison	1
Danube	1	Mace No. 2	½
Hill Annex	2†	York	½
Majorca	½	Shada	½
Draper	½	La Rue	½
Patrick	1	Crosby	½

A one-unit plant contains two 25-foot and four 18-foot log washers, with the necessary tables for the fines. In general, it may be said that twelve double-deck tables are required for each unit. The mills are all of the same general type, having in most cases been patterned after the Oliver Iron Mining Company's plant at Trout Lake. Minor changes have been made to some extent. Page 130 shows a flow sheet that is applicable to almost any one-unit plant now under operation. According to the flow sheet, the coarse material (taconite) is separated by use of grizzly bars, whereas at some plants it is removed by hand either before or after entering the screen; but hand-picking the taconite seems preferable where the crude ore contains any large hematite boulders or a small percentage of oversize, although a careful study of the ore body will indicate which is the better method.

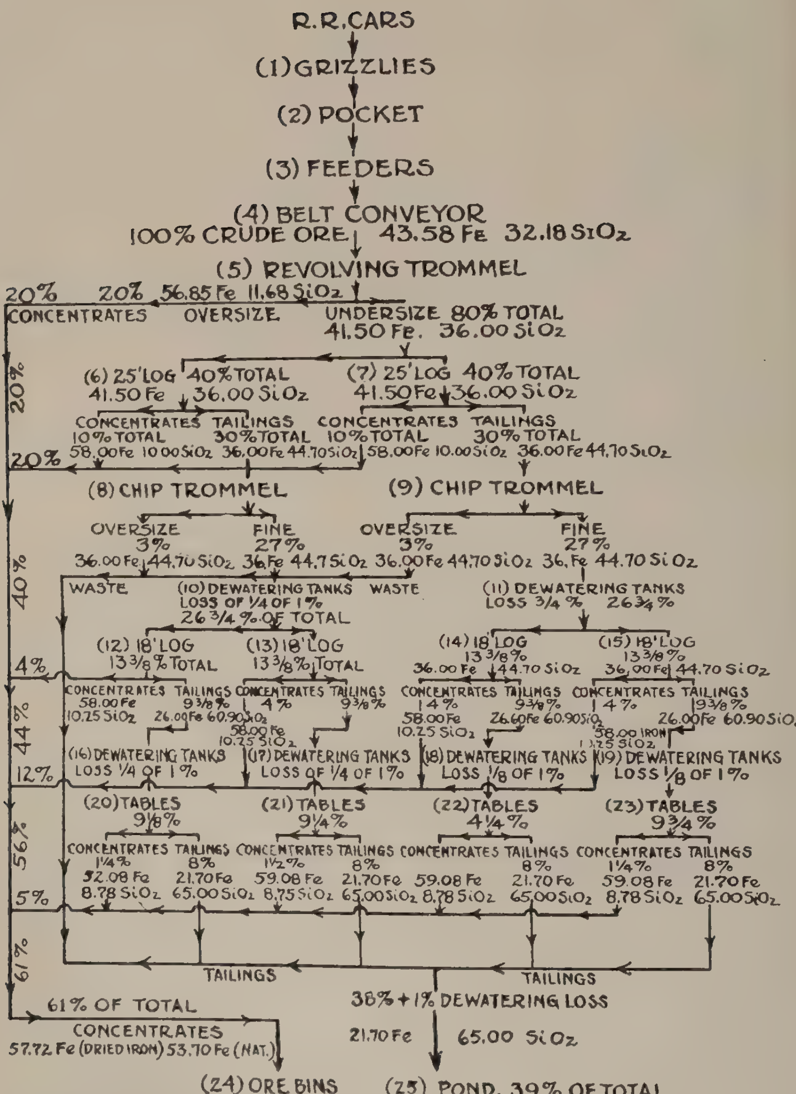
†Planned.

*Abstract of article by F. A. Kennedy: Eng. Min. Jour., vol. 107, 1919.

I have seen ore taken from a large pit which, when washed, gave but one twenty yard car of rock to forty-five cars of concentrates, whereas treatment of other material from the same pit has yielded one car of rock to every car of concentrates. In the latter case it would be impossible to pick the rock out by hand and make any headway.

In a one-unit plant the main conveyor belt that carries the ore up to the head of the belt is usually thirty-six inches wide, and should have a speed of about 240 feet per minute on favorable ore. It is hardly possible to carry all the ore the plant can handle on a thirty-six inch belt with a speed of 180 feet per minute, which was the original speed adopted in a number of plants. A higher speed than 240 feet per minute is unnecessary and shortens the life of the belt. Examination of several discarded belts showed that the material was only partly worn out, although in most cases it was torn or ripped by either a sharp piece of taconite or steel. Such damage can be prevented by allowing plenty of clearance along the return part of the belt and plenty of headroom underneath the lower pulley.

There is a variation in the size of openings in screens or trommels, but the average size for such work is a full punch, ⅜-inch plate with 1½-inch holes. On the average wash ore, however, this is too large an opening; and at some of the newer plants, such as the Draper and the Mace No. 2, 1¼-inch screen openings are provided. For a good grade of wash ore, it would be well to use screens with ⅞-inch openings, as the former sizes put too heavy a load on the log washers, with the result that the oversize is but a small proportion of the total, whereas it should equal about 20 per cent. By bolting a 1½-inch screen inside of another, and staggering the holes, it is possible to double the oversize without varying the grade of the concentrates, and by doing so I increased the capacity of one of the plants about 25 per cent. A full-punched ⅞-inch screen has since been purchased to replace the above mentioned apparatus. At another plant, instead of altering the screen temporarily, the undersize from the first half of the screen went directly to the 25-foot logs and the remaining half to the concentrate bins. This change did not make an appreciable difference in the grade, but resulted in the addition of a considerable volume of water to the concentrates. A close study of the character and structure of the ore should be made before determining the screen mesh to be used. From results obtained at several plants, it appears that it is



Flow Sheet Of One-Unit Iron-Ore Washing Plant, Showing Approximate Percentages And Analyses.

tter to have the large screens driven by a gear placed parallel the axis of the screen, than by one at right angles and on e front face.

The undersize passes directly to the 25-foot log washers. ne first half of the screen should discharge in the center of e log and in a manner that will not wear out the shaft angles. nis may be done by placing a baffle so as to produce a spray. ne second half of the undersize should enter near the head of e log, as there is usually but a small amount of remaining nd to be washed out, and by this arrangement the work on the g is lightened. Both the 25-foot and the 18-foot logs should provided with friction clutch pulleys, which are essential, for the power is suddenly cut off, or the belt breaks, it is a two three hour job to clean out the washer before it is possible turn the log over again. A 2½-inch hose with a nozzle is und useful for cleaning out and can be handled best through a anhole in the bottom, near the tail end of the log.

The tailings pass into a chip screen or trommel (the over-ze going to the waste pond and the undersize to the 18-foot gs) provided for the purpose of removing chips, cinders, and coarse particles that would otherwise plug up the spigots of e machinery subsequently employed. It seems better practice use a ⅜-inch wire screen instead of full-punched screens. No ubt there is a larger loss on fines with the ⅜-inch punched reen, commonly used, than in any other part of the mill, so at if it is necessary to use punched screens of that size, a nger screen should be installed. The oversize is 50 per cent od ore, which should be saved, for the loss probably amounts twenty or forty tons per day and could be recovered by put-ng in a two or three cell jig.

The undersize from the two chip screens is dewatered and e products from the spigots go directly into the four 18-foot ashers. These operate at a lower speed than the 25-foot log ashers and require less repair work. The heads from this eration run into the concentrate bins, and the tailings, after ing dewatered, are distributed over twelve double-deck tables. ngle-deck tables were used at first at all the iron ore washeries, t later the double-deck table was adopted as an economy.

The Hawkins plant, at Nashwauk, uses classifiers in the ttom of a small tank at the tail end of the 18-foot logs. A arse concentrate is drawn off, thereby lightening the load on e tables. This is good practice, and should be followed by other

plants. In mills where the concentrates run extremely low in silica, as at the Patrick, it seems advisable to replace the tables by classifiers, but the product from the last two spigots of the classifiers should be run over tables. In this way, not only as many iron units go into the concentrates as formerly, but an additional tonnage of silica is added, which does not influence the grade to the extent of more than 2 per cent. However, for those not familiar with the use of classifiers, I believe it best to use them in conjunction with tables. In other words, it is advisable to treat on a separate table every spigot discharge from a classifier that is not clean, as outlined on the flow sheet on page 134.

The Draper mill is installing a dewatering device for all the fine concentrates. Should this prove as successful as hoped, it will no doubt be adopted by other mills, as the present method results in too much water being sent to the railroad cars. The water readily drains out, but in filling the cars a large loss of fine ore results. Some mills have installed a sloping platform underneath the loading track which has an outlet into a large elevator boot. The fine ore and water that drips from the cars is then hoisted up to a dewatering tank by means of a belt elevator, and the process not only saves the fine ore but reduces the number of men needed in front. From experience it is found best to use a fairly large pulley, 48-inch, at the bottom and top; 7″ x 12″ buckets, spaced at 16 inches, will handle the overflow from a one-unit plant.

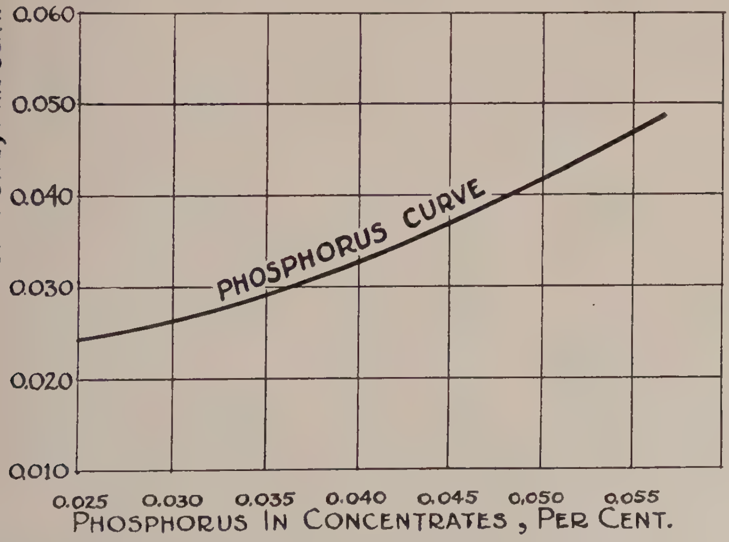
The most important and essential factor for the operation of a washing plant is an ample, continuous supply of water. It is far better to be safe on the water question, in every possible manner, than to be near the limit of just having enough. In some instances pumps have been installed with ample capacity, but the discharge line was of such size that it was almost impossible to run the mill at full capacity. Automatic stopping and starting devices should be installed, not only on the pump motors but on all mill motors, and they should be as nearly "fool proof" as possible. Pumping more water than needed is wasteful. A discharge pipe of ample capacity should be provided, together with a check valve and a safety valve, preferably of the spring type. If the discharge line is long, an air-inlet valve should be placed in the discharge pipe. The automatic stopping device should be so arranged that when any concentrating machine or motor stops in the mill, all the machinery controlling prelim-

ary operations will cease automatically. Proper lines of com-
unication by both bells and telephones should also be provided.

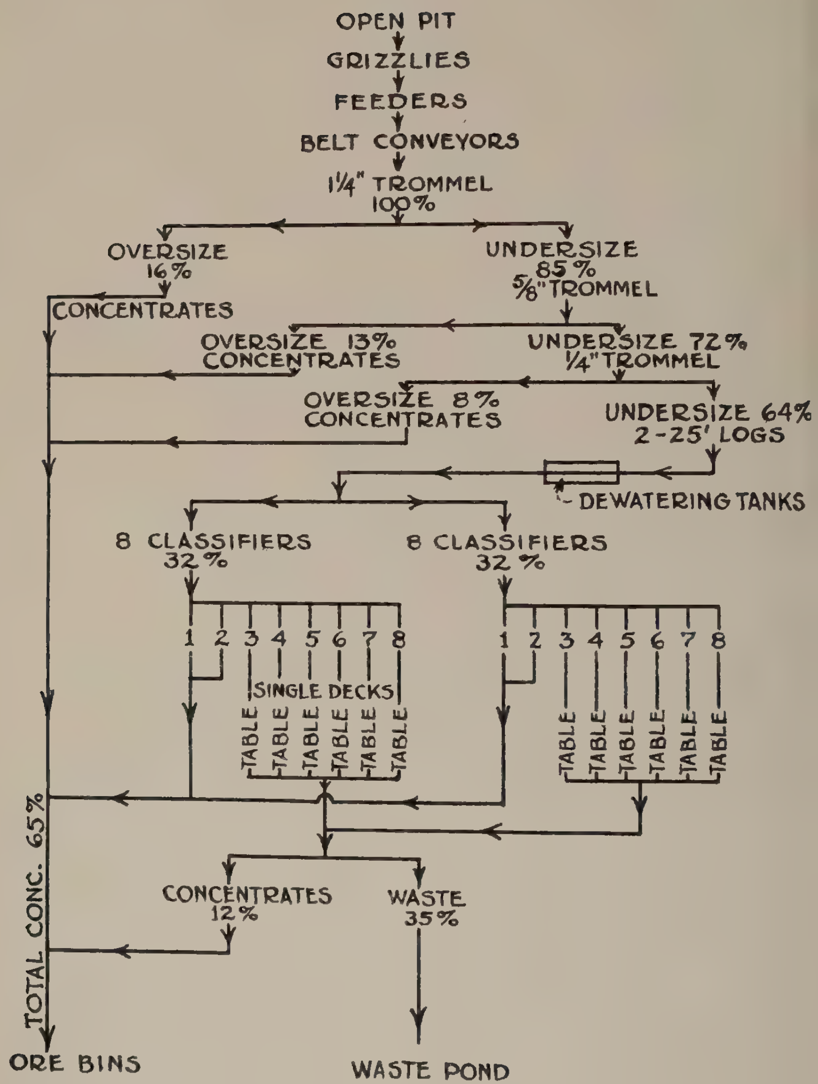
The figure below is a curve diagram in which the phosphorus the crude ore is represented by the abscissas and that in the ncentrates by the ordinates. Knowing the phosphorus content the crude ore, the approximate phosphorus per cent in the ncentrates can be determined.

The flow sheet reproduced on page 134 is a possible treat-ent scheme for ores that show by a screen analysis that a mmercial concentration can be made. I have not attempted give the exact size screens that should be used, but have ven the approximate size openings and the percentage of total aterial that each would necessarily have to handle.

The curve shown on page 135 represents the average analysis a number of samples taken from different mines, and indicates at all oversize on a 40-mesh screen will analyze approximately .82 per cent dried iron, and 11.75 per cent silica, which is a od grade of concentrate. Considering this, it would appear at a plant constructed after such a screen flow sheet would be tisfactory, but it is doubtful whether any operating company the iron ranges would look with favor on such a radical ange. In making up the flow sheet on page 134, I have carried it the screen idea down to the ¼-inch size. Instead of using



URVE SHOWING RELATIVE PERCENTAGES OF PHOSPHORUS IN CRUDE ORE AND CONCENTRATES

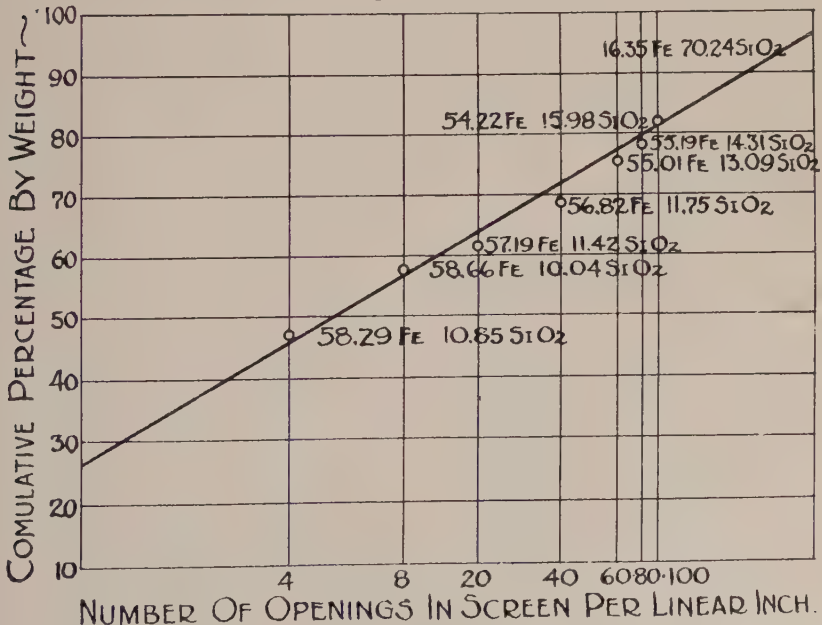


FLOW SHEET FOR IRON ORES WHICH SHOW A COMMERCIAL CONCENTRATION BY A SCREEN ANALYSIS • — •

four 18-foot logs, such as were used to handle the fine material passing through the chip screen, I have shown two 25-foot logs only. In the present plants a study of the 25-foot logs shows that they will handle from 50 to 60 per cent of the total concentrates. This product will contain from 60 to 75 per cent of the concentrate that screens between 20 mesh and 100 mesh. In other words, the 25-foot logs show a good recovery on the larger percentage of the fines. For treating the remaining fines or tailings from the 25-foot logs, which represent from 40 to 48 per cent of the total crude ore, I have placed a series of eight classifiers following each 25-foot log. One or two spigots could be drawn off and each following spigot treated on a separate table.

There is not much material difference in the headroom required for either plant. There is, however, a difference in the cost, and this is due largely to the fact that the flow sheet on page 130 requires more machinery than the plant represented by the flow sheet on page 134. The first plant has four 18-foot logs, two chip trommels, and twelve double-deck tables, and this

CURVE SHOWING SCREEN ANALYSIS ON SEVERAL SAMPLES TAKEN IN THE NASHWAUK, MINNESOTA, DISTRICT



equipment in the latter is replaced by two screens (5/8-inch and 1/4-inch), one 25-foot log, sixteen 6-inch classifiers, and two single-deck tables.

For small ore deposits where the installation would not warrant a standard 1/2-unit plant, another 1/8-inch screen would be added below screen No. 3 in the flow sheet on page 134, and this can be followed by classifiers and tables. There are some small wash deposits on the Mesabi range that can be treated profitably by means of such an installation.

In the matter of costs, at one plant crude ore was treated for 5 3/4 cents per ton, the cost including operating, repairs and office expenses, but not depreciation. Another one-unit plant, exclusive of depreciation, shows the highest cost per month for one season to be 9.41 cents per ton of concentrates. In making estimates on probable costs per ton, including depreciation (which is determined by the tonnage of ore to be treated), it should not run over 15 cents per ton of concentrate, or 9 3/4 cents per ton of crude ore.

THE COLERAINE CONCENTRATING PLANT*

The construction and erection of the Coleraine concentrating plant was commenced in April, 1909, and was completed (with the machinery installed) ready for use in 1910. Attached to the main building is a table house large enough to accommodate concentrating tables for five units and space for a small machine shop and supply store. For the handling of the railroad cars in the upper portion of the mill there is provided on the north side of the main structure a trestle approach 650 feet long, and on the south or opposite side a tail track 300 feet long. The latter is so constructed as to permit its being incorporated directly in a possible future extension of the plant. The building, viaduct approach and tail trestle, as well as the table house, are constructed of steel, the total amount used being 6,100 tons. The building is covered by corrugated steel sheeting over 2 x 6-inch wood sheathing fastened directly to the structural steel. The north end of the trestle approach is connected with the main road-beds forming the track system for delivery of the crude ore to the plant over an embankment of a maximum height of 110 feet containing over 2,000,000 cubic yards of dirt. On the east

*Abstract of article by J. U. Sebenius: Proc. L. Sup. Mg. Inst., vol. 18, p. 155.

side of the building is arranged a system of concentrate tracks connecting with ample storage yards for both loads and empties. The delivery tracks over the crude-ore bins are ninety feet above the tracks receiving the concentrates.

While not intended for winter operation, the mill building is equipped with a high pressure heating system, the steam for which is supplied by a small boiler plant located in the immediate vicinity of the mill.

All inside wiring is placed in conduits. A traveling crane electrically operated over a track extending the entire length of the building provides for handling the heavy machinery.

Water Supply. Water is obtained from the lake through a 40-inch steel intake pipe, 400 feet long, and is conducted through a 30-inch lap-welded steel pipe to a 100,000-gallon cylindrical steel tank at the mill. The water pressure on the various floors of the mill varies from 20 to 75 pounds per square inch.

Concentrating Machinery and Appliances. As the mill stands today the plant contains five independent units and appliances. Each individual unit is made up of two half units which are dependent on one another only in bin and screening capacity. This arrangement was adopted to prevent delay in the entire mill and in each separate unit—should break-downs occur. Installment of individual units was also necessitated by lease conditions requiring that ore from each property be handled separately. All units are entirely similar in construction, but were installed at various times, the first and second units being erected in the spring of 1910, the third in the fall of the same year, the fourth and fifth completed at the beginning of the season 1911. Precaution was taken to eliminate from the mill construction all light and unreliable machinery such as link belts, chain elevators, conveyors and automatic feeding appliances.

Each individual unit is made up as follows: At the top of the mill and directly under the crude ore tracks, for each unit there is a receiving bin with a capacity of about 500 tons crude ore. At the discharge end of this receiving bin is a grizzly—steel rails spaced 12-inch centers—and also a hydraulic nozzle connected to the water system. Under the grizzly is a rock pocket. The hydraulic nozzle is capable of discharging into the receiving bin, at the direction of an operator, a heavy stream of water under a pressure of thirty-three pounds per square inch. The bin extension under the grizzly is through an apron directly connected with one conical, revolving screen or trommel having

two-inch perforations. Passing through the center and along the entire length of this trommel is a spray pipe. The size of the trommel is: Length, twenty feet; diameter at the small end, four feet; at the larger end, eight feet.

Directly below the large end of the trommel is placed a conveyor belt thirty-six inches wide and twenty feet long to take the over-size material from this screen. Directly below the trommel is constructed a bin or junction-box divided into two compartments into which falls the under-size material. On each side of this bin and below the same and at proper distances and elevations are placed two log washers, each taking one-half of the under-size material delivered into the junction box from the trommel. The size of these log washers is: Length, twenty-five feet; width, six feet eight inches; depth, three feet. They are placed at an incline of one inch to the foot, and are each provided with twin logs with chilled cast iron paddles. Their bottom is constructed so as to provide for three hutches covered with perforated steel plates through which a strong current of water under a pressure of fifty pounds to the square inch is forced. The waste material coming over the overflow end of the log washers contains chips, waste and other material, and for this reason a chip screen has been placed directly behind each log washer. Directly under these log washers are placed three steel settling tanks, Nos. 1, 2 and 3, at different elevations. Located directly under No. 1 tank on each unit is placed one smaller log washer locally known as a "turbo." The size of these turbos is as follows: Length, eighteen feet; width, four feet; depth, one and one-half feet. These turbos are of the same general construction as the larger log-washers, being provided with a rising water column forced under pressure through hutches and hutch-plates.

The tanks above referred to are "V" shaped. Tank No. 1 is five feet in width by eight feet in length and four and one-half feet deep. Tanks Nos. 2 and 3 are six feet in width, sixteen feet in length and five and one-half feet deep. All are provided with spigots for the discharge of the accumulated material.

In the table house at some distance below these three steel tanks are located four batteries of five Overstrom tables, arranged in two parallel series. Each of the twenty concentrating tables is fourteen feet in length and six feet wide along end lines, and is provided with riffles, which on some tables are constructed of wood and on others of rubber.

To convey the table concentrate from the table house, two 54-inch Frenier spiral sand pumps are installed in each half unit. These pumps discharge into a de-watering tank located immediately above the bin into which is assembled all the concentrate from all machines constituting the unit. This de-watering tank is also of steel, "V" shaped, top width seven feet, length twelve feet, and depth five and one-half feet.

The conveyor belt above referred to is known as the "picking belt." On each side of it is located a steel chute leading to what is known as a "rock pocket" made of steel. This discharges into cars below. These cars are hauled by an electric locomotive to a rock dump a short distance beyond the confines of the plant, over a track system overheading the main shipping tracks on the west side of the plant.

The concentrate receiving bin is large enough to accommodate the entire unit, built of wood and lined with steel plates, and has a capacity of about ninety tons. This receiving bin is provided with discharge lips through which this concentrate passes into railroad cars on the tracks below.

The following arrangement gives the power distribution for the unit: One 100-horsepower motor is used for driving the cone-shaped trommel, two log washers and two turbos. One 15-horsepower motor is used for driving the concentrating table and chip screen. One 20-horsepower motor drives the four Frenier pumps serving the unit.

The concentrating equipment in each unit thus includes:

One receiving bin.
One grizzly.
One conical screen.
One belt conveyor, or picking belt.
Two 25-foot log washers.
Two 18-foot log washers.
Six steel settling tanks.
Two table wash-water tanks.
Twenty Overstrom concentrating tables.
Four Frenier pumps.
Two steel de-watering tanks.
Two rock pockets.
One concentrate bin.

Safety Devices. The great amount of thought which has been put into safety devices, and the minute detail into which those in charge have gone, make impossible complete description

in a paper of this kind. Therefore only the more prominent features will be described, and perhaps the most simple course to follow will be the one most commonly used, that is, the route of the ore.

The first application of a safety feature is in preventing the crude ore from falling through the approach trestle from the cars to the ground. The great height of this trestle would make an injury from this source very serious. This is prevented by a decking which also eliminates danger of fire from the sparks of passing locomotives. A structural steel hand-railing extends the entire length of the trestle on both sides and is supplemented by a toe-board at its bottom.

Within the building, at the receiving bins, the most apparent features are, first, the peculiar arrangement of railings and walks which compels the workman unconsciously to guard himself from passing trains, and second, the covered stairways and landings by which sluicer helpers are enabled to work beneath the tracks with safety and freedom.

Within the mill proper, at a point where the ore is washed from the bins into the revolving conical screens, are placed large heavy hinged gates and a stationary wall which serves as a sort of breastwork in front of the sluicer. The stationary walls afford the worker safety from sudden slides of ore while sluicing, and the hinged door protects him from the same danger when ore is being dumped into the bin.

At the picking belts are provided hoppers located conveniently near both the belt and the men. While these are built up high enough to greatly facilitate removing the waste rock from the belt, their primary purpose is to prevent the men from falling into the pockets beneath. The chutes from these pockets which receive the waste rock were provided with the customary quarter-pan or pocket stops, but as these did not prevent small pieces from rolling out beneath them down on to the heads of passersby, it was necessary to provide an additional means to prevent this. Such a device consisted of a special counterbalance gate or dam made of steel plate. The peculiar location of the stop itself and the point from which it was to be operated made this a difficult problem. The electric tram cars which carry the rock from these chutes to the dumps are provided with automatic gongs which ring when the cars are in motion and warn the workmen of their approach.

The next point of possible danger in the course of the ore is in the discharge from the log washers. The problem here was somewhat difficult, for in order to inspect properly the concentrated product the workmen had to stand between large revolving gears on one side, and the moving blades of the washers on the other. However, the difficulty was solved by means of gear housing and platforms in such a manner as to make this point very accessible and at the same time remove both danger and fear of injury.

On the table floor, the driving-head gear of the machines presented the chief source of danger. To obviate this, frames built of pipe and covered with removable steel plates were placed around the driving mechanism. This secured safety and accessibility. Shifting levers for the belts, so designed as to be simple and free from projecting parts, were attached to these frames.

In the basement the only point which was considered dangerous, and this on account of darkness rather than location, was the driving mechanism of the Frenier pumps. The installation of steel geared housings, wooden troughs for belts and a generous lighting system, did away with all danger at this point.

There are many miscellaneous devices which, though not so intimately connected with the operation of the mill, are none the less necessary. The most important of these are the coverings of every gear, belt, pulley, and moving part throughout the mill, and the safety collars on all shafting. Enameled iron signs warning operators are placed at every conceivable point of danger. Signal bells are sounded when starting all mill machinery, so that every working man may protect himself if in danger or invisible to the operator. Permanent stair-like platforms were constructed beneath the receiving bins, to enable workmen to remove the bolts that hold the wearing plates when repairing them. Stairways were everywhere provided rather than ladders, and all of them were covered at the backs, thereby preventing material from falling or being kicked through them on to the heads of persons beneath. But perhaps the greatest of all provisions for the protection of the working man in his routine duty about the mill is the most carefully planned and permanently constructed system of railed walks. These lead everywhere. They are rigid and strong to the last degree. Their railings are of steel pipe, their stringers and joists are of steel beams. Their treads are of the heaviest matched flooring, and their sides are protected by the ever-efficient, though obscure, toe-board. Records show that

in this item alone, 32,300 lineal feet of 1¼-inch standard pipe with the necessary fittings, and 12,450 lineal feet of 2x8-inch surface pine boards have been used. Not the least of the factors which makes this provision one of the most worthy of the safety devices in the sense of security which the workmanship apparent in it engenders.

Production. The total amount of concentrate produced by the various machines in the unit depends largely on the character of the crude ore treated. The following table will, however, give a general idea thereof:

	Per cent.	
Belt product	3 to 35	Depending on character of crude ore.
Two logs product............	60 to 85	
Two turbos product..........	2.5 to 10	
Twenty tables product.......	1.5 to 6.5	

Concerning the size of the product obtained, it may be stated that the belt product is all larger than 20 mesh. Of the log product 90 per cent is coarser than 40 mesh and 4 per cent finer than 100 mesh. Of the turbo product 15 per cent is coarser than 40 mesh and 32 per cent finer than 100 mesh. Of the total table product 85 per cent is finer than 100 mesh and 50 per cent is finer than 200 mesh.

These figures will indicate the care which has been taken in the processes, in the construction of the plant and of the various machines therein, to effect a saving commensurate with good practice, economy and furnace requirements.

MAGNETIC CONCENTRATION OF EASTERN MESABI IRON ORES

The deposits of the east end of the Mesabi range cover very large areas, and consist of the same taconite that produces the hematite of the central and western Mesabi. It is not deeply covered with drift, but outcrops boldly in large masses. It is not concentrated locally into enriched bodies separated by leaner areas, but is all a fairly uniform, hard, banded, unaltered chert, carrying about 25 to 30 per cent iron as magnetite.

The Mesabi Iron Company, organized by Hayden, Stone & Co., and under the direction of D. C. Jackling, has taken over these deposits and is building a concentrating plant at the new town of Babbitt, about fourteen miles east of Mesaba, Minn. This plant is to have a capacity of 2,000 to 3,000 tons per day,

and is based on the application to this low grade material of the methods which have made the so-called porphyry copper properties so successful.

In 1916, an experimental mill was built in Duluth, containing full sized machinery and capable of handling from 100 to 200 tons daily. A considerable tonnage of material was concentrated here during 1916, 1917 and 1918. The work showed that the resulting product could be varied, almost at will, between 60 per cent and 70 per cent iron and .006 per cent to .030 per cent phosphorus, and that this could be made on a large scale well within the limits of cost set by iron trade conditions. A small special cargo was sent down the lakes, late in 1918, assaying 63.27 per cent iron (natural and dry) and .008 per cent phosphorus, but it is assumed that large scale shipments will normally be of a Bessemer grade carrying about 63 per cent iron and .020 per cent to .030 per cent phosphorus. This material is a sinter, carrying only traces of sulphur and titanium, with silica between 6 per cent and 10 per cent, and alumina, lime, magnesia, and manganese, each below 1 per cent. Some of the iron in this sinter is hematite and some is magnetite, the percentages varying according to the treatment given on the sintering machine. Like the analyses, this hematite percentage is within reasonable control. Sinter made from finely ground magnetite has much the structure of coke, being firm yet porous, and gives good account of itself in the blast furnace.

The methods to be used in the plant now under construction are about as follows:

(1) Stripping—very light. Much of the deposit has no covering at all.

(2) Quarrying—side hill work. Faces forty to sixty feet high. Churn drill holes and heavy blasting.

(3) Steam shovel—100 to 120 ton.

(4) Standard gauge railroad, quarry to mill.

(5) Extra heavy primary crushing plant to two inch size.

(6) Dry magnetic separators in closed circuit with 72″ x 20″ rolls, reducing to about one-eighth inch size, and discarding about 50 per cent of the material as hard waste rock of all intermediate sizes, suitable for concrete work, road building and railroad ballast. A shipping concentrate can also be taken out here and shipped without further treatment, if desired.

(7) Ball mills, grinding the one-eighth inch partly concentrated material, wet, to 80 to 100 mesh.
(8) Wet magnetic separators, Davis type.
(9) Sintering plant, Dwight-Lloyd machines.

No one of these operations is novel or untried. Each is in successful use somewhere else, with costs and results well known.

The quarry, railroad and coarse crushing part of this plant will be in operation in the late fall of 1920, if labor and railroad conditions permit. The entire plant should be in production during the entire season of 1921. It is being built on the unit basis, so that additional capacity may be added at will up to almost any amount desired.

The crude ore assays 25 to 30 per cent of iron in the form of magnetite; the coarse tailing from the cobber plant, 3 to 6 per cent of iron as magnetite; the fine tailing from wet separators, 0.2 to 0.7 per cent of iron as magnetite; and the sinter, 60 to 70 per cent of iron, 6 to 9 per cent of silica, .006 to .030 per cent of phosphorus, traces of sulphur and titanium, and small amounts of alumina, lime, magnesia and manganese. The sinter is to be sent to the blast furnaces at Chicago, Cleveland and Pittsburgh, by rail and lake, just as other iron ore from the Lake Superior region.

This is an experimental plant, although of commercial size, and its success is of immense importance to the iron and steel industry of the country.

LAKE SUPERIOR IRON ORES

The iron ores of the Lake Superior region are found almost exclusively in rocks of Huronian age, the only exception of importance being in the Vermilion district. It may be estimated that about 95 per cent of the ores thus far mined have been obtained from Huronian rocks. Although these ores come from rocks of varying age and slightly varying type, they have many features in common, and therefore may readily be described together.

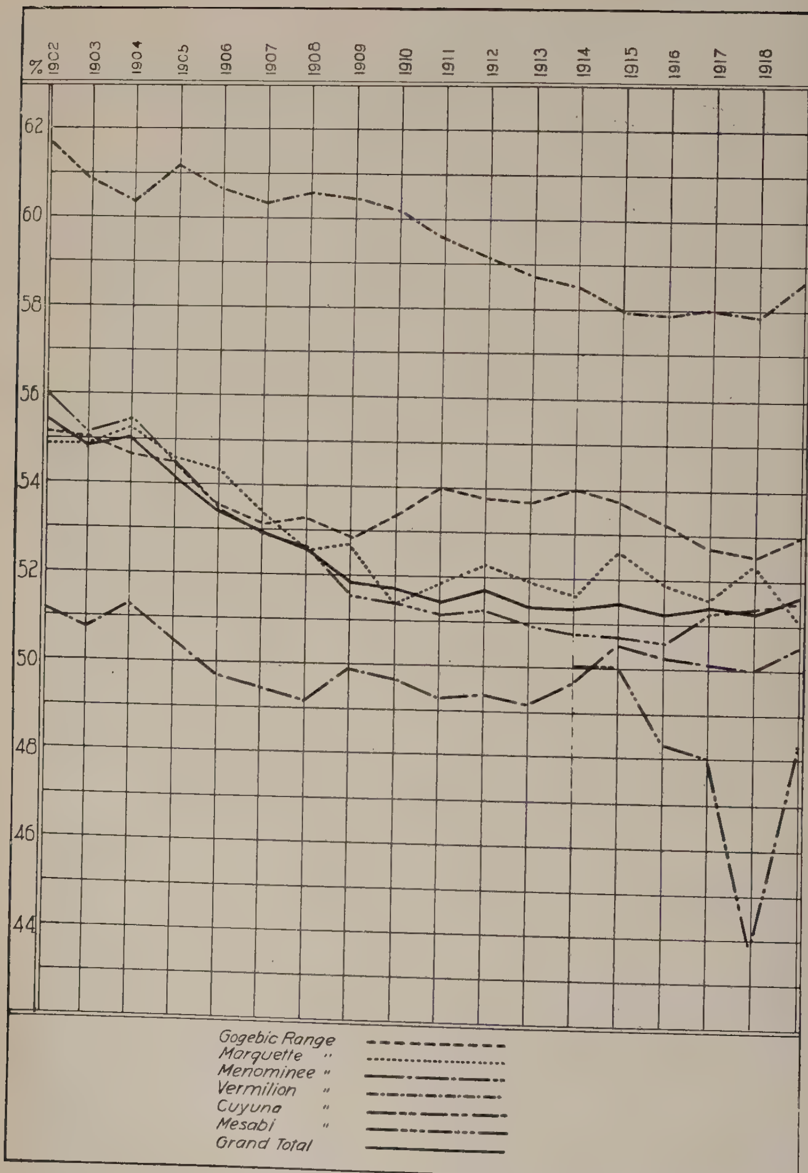
The iron formations of the Lake Superior region consist essentially of interbanded layers of mixtures in widely varying proportions of silica and iron oxide, and are called taconite, ferruginous chert, or jaspilite. They vary considerably in hardness and color, depending upon the tenor of silica and the history of the rock. Local phases of the iron bearing formation consist

of cherty iron carbonates, greenalite or ferrous silicate rocks, amphibole-magnetite masses, cherts and slates, and pyritic quartz rocks. The average iron content of all the original phases of the iron bearing formations, excluding interbedded slates, is about 25 per cent, while the average iron content for all portions of the formation, whether in the original condition or not, is about 38 per cent. It is believed that this difference is due essentially to the removal of silica in solution from the primary phases, and, of course, such removal of silica has in many cases produced material now used as iron ore, since it contains considerably more than 38 per cent of iron.

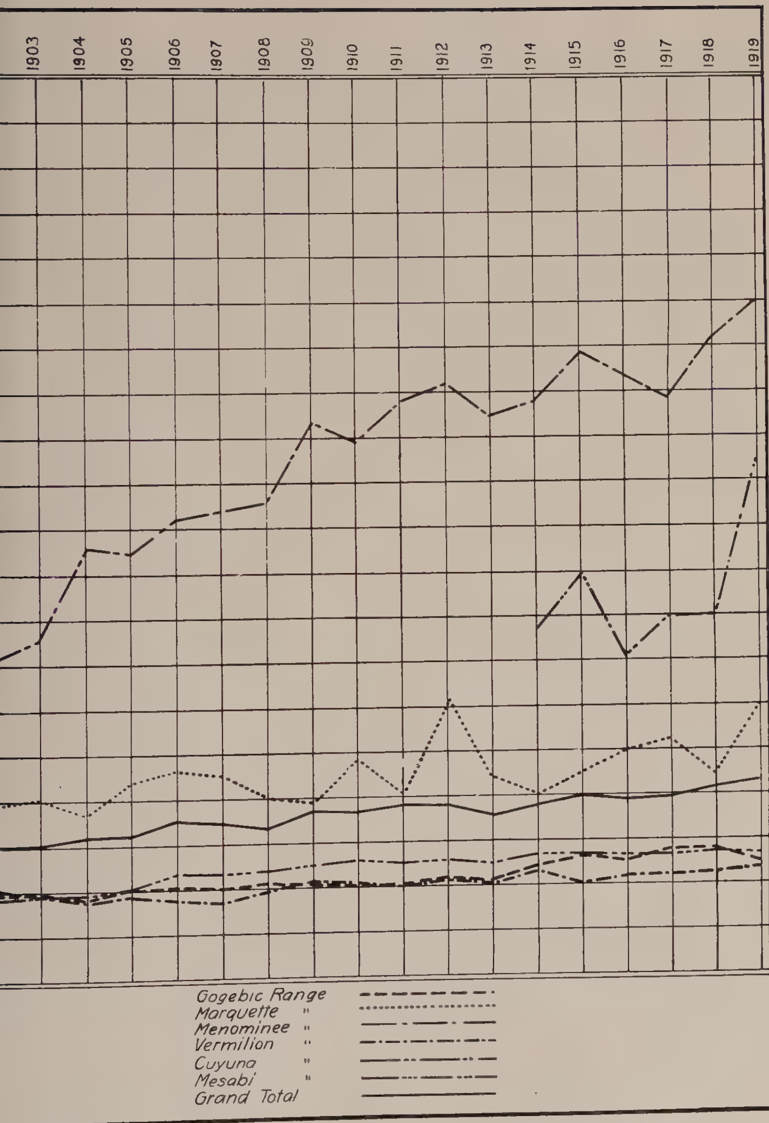
The iron ore bodies of the Lake Superior district are of the widest variety in shape and size. They may be roughly tabular in a horizontal plane, as in the Mesabi district, or in steeply inclined planes, as in the Menominee district; or they may assume almost any combination of forms; and the variety is very great. The horizontal dimensions known at the surface reach a maximum of about a mile, though deposits more or less connected are known for a distance of ten miles near Hibbing. The maximum depth of iron mining is more than 2,200 feet on the Gogebic and Marquette ranges.

The ore deposits are closely associated with ridges or hills, a fact that explains the common use of the term "range" in connection with the iron districts. The most important exception to this relation is in the Cuyuna district of Minnesota, where no relation can be found between the present topography and the ore deposits. It is probable that this association of ore deposits with hills is due to the fact that the hill slopes are places where circulating waters have considerable head and are therefore more active.

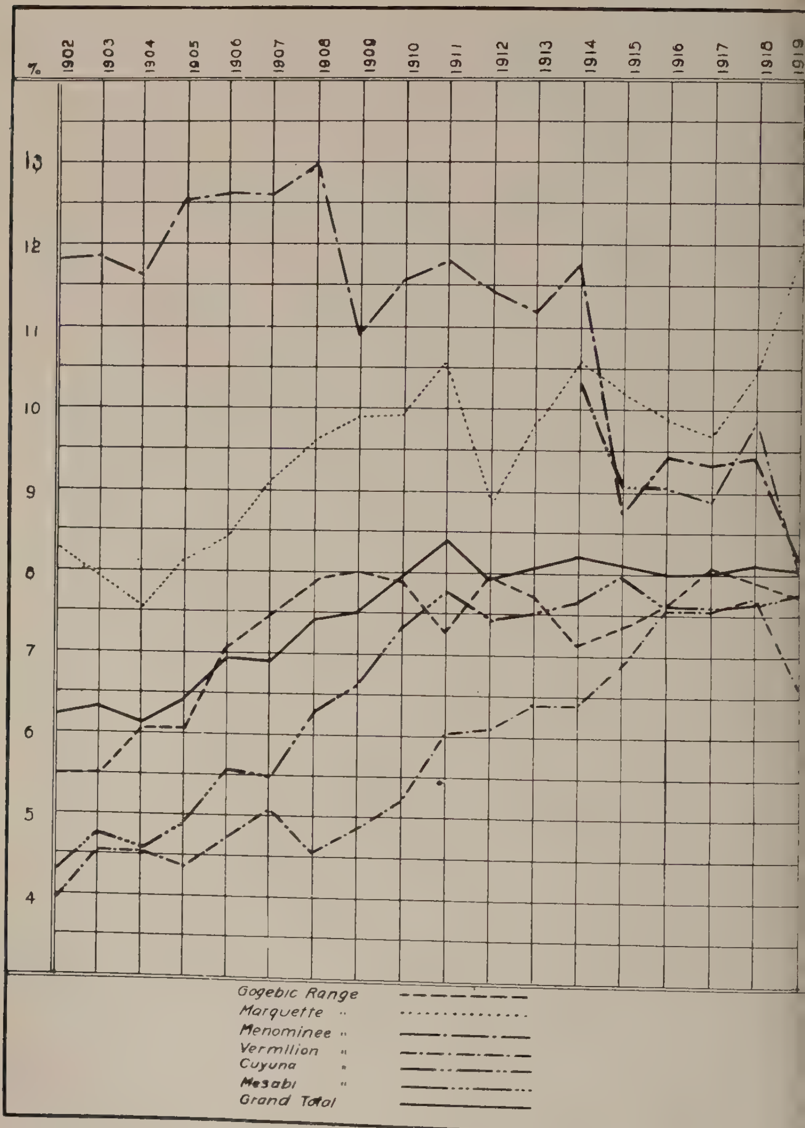
Composition. The average composition of all the iron ores mined in the Lake Superior region has been carefully worked out by the Lake Superior Iron Ore Association of Cleveland. These averages are obtained by combining all grades of ore in proportion to their tonnage, and are very instructive in many particulars. Graphs showing the results obtained are given on pages 146-149. One of the most interesting deductions that can be drawn from these graphs is that the average content of iron in all ores of the region, as mined from year to year, has fallen from 55.4 per cent in 1902 to 51.3 per cent in 1918; but it may also be noted that the decrease in iron percentage took place almost wholly between the years 1902 and 1911, and it may be



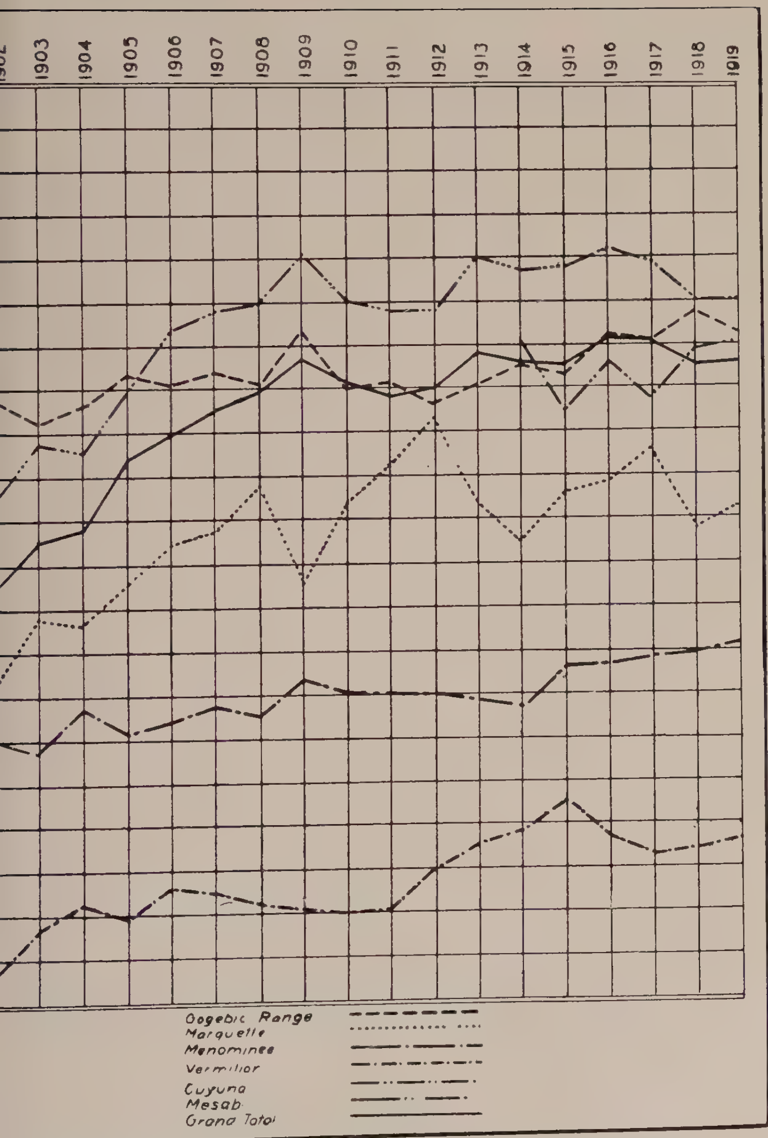
Average iron contents of Lake Superior iron ores, 1902-1919.
From Lake Superior Iron Ore Association.



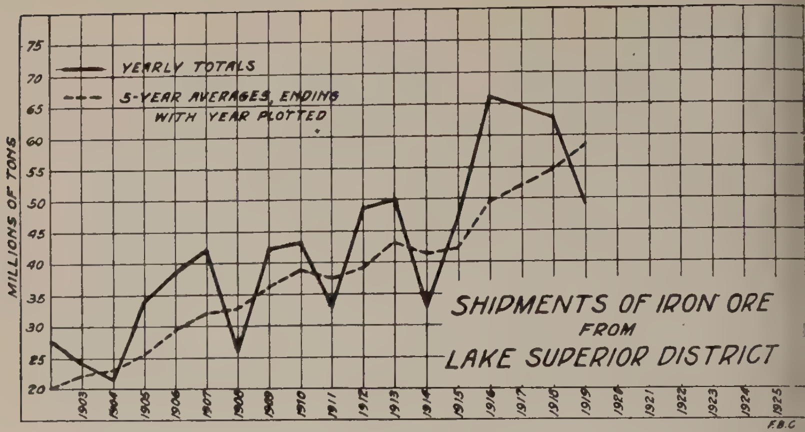
Average phosphorus contents of Lake Superior iron ores, 1902-1919. From Lake Superior Iron Ore Association.



Average silica content of Lake Superior iron ores, 1902-1919.
From Lake Superior Iron Ore Association.



Average moisture content of Lake Superior iron ores, 1902-1919. From Lake Superior Iron Ore Association.



Shipments of iron ore from Lake Superior District.

concluded that the rate of decrease in iron percentage is itsel decreasing. Nearly all other constituents of the ores have beer increasing during the same interval of time. This is especially important as regards the increase in phosphorus, which has beer very marked in the ores of the Menominee range and only sligh in the ores of the other ranges. The average content of manganese has increased in the ores of the whole district, but this ha been due largely to the increase in the ores of the Mesabi range and, recently, to the large amount of manganese in ores from th Cuyuna range. The average per cent of moisture has increasec from 8.7 in 1902 to a maximum of 11.6 in 1916, and this, agair has been due in large part to the ores of the Mesabi range, bu the same tendency is evidenced by the ores of all the other range

The mineral composition of the ores of the district is relatively simple. The iron ore minerals include only the following

(1) Magnetite, or magnetic oxide of iron; compositio Fe_3O_4, containing theoretically 72.4 per cent iron.

(2) Specularite, also called hematite, or ferric oxide of iron composition Fe_2O_3, containing theoretically 70 per cen of iron.

(3) Hematite, also commonly called brown hematite, amor phous ferric oxide of iron, containing a small but signif cant amount of water, and grading into

(4) Limonite, turgite, goethite, or mixtures of these wit each other or with hematite, having the composition c ferric oxide with more or less water, and a theoretica tenor of iron of 60-66 per cent, depending upon th degree of hydration.

(5) Siderite, or iron carbonate; composition $FeCO_3$, locally called spathic iron or black band ore, etc., containing theoretically 48.2 per cent of iron.

It has been estimated that more than 90 per cent of the ore consists of hematite and limonite, as described above, and about 5 per cent consists of specularite.

Many of the Lake Superior ores are slightly magnetic, but there are only two mines which ship ores classed as magnetite ores, namely, the Republic and Champion, and even these mines ship ores which are largely specularite with considerable admixed magnetite; but at the present time the true magnetite ores of the eastern end of the Mesabi range are being developed and large quantities will be shipped from this region in the future. The magnetite ores consist commonly of coarse grained mixtures of magnetite and quartz with much smaller amounts of a considerable variety of other minerals, especially silicates, such as amphibole, pyroxene, garnet, chlorite, olivine, etc. The minerals of these ores show greater variety and more complex constitution than do those of the softer ores containing little if any magnetite.

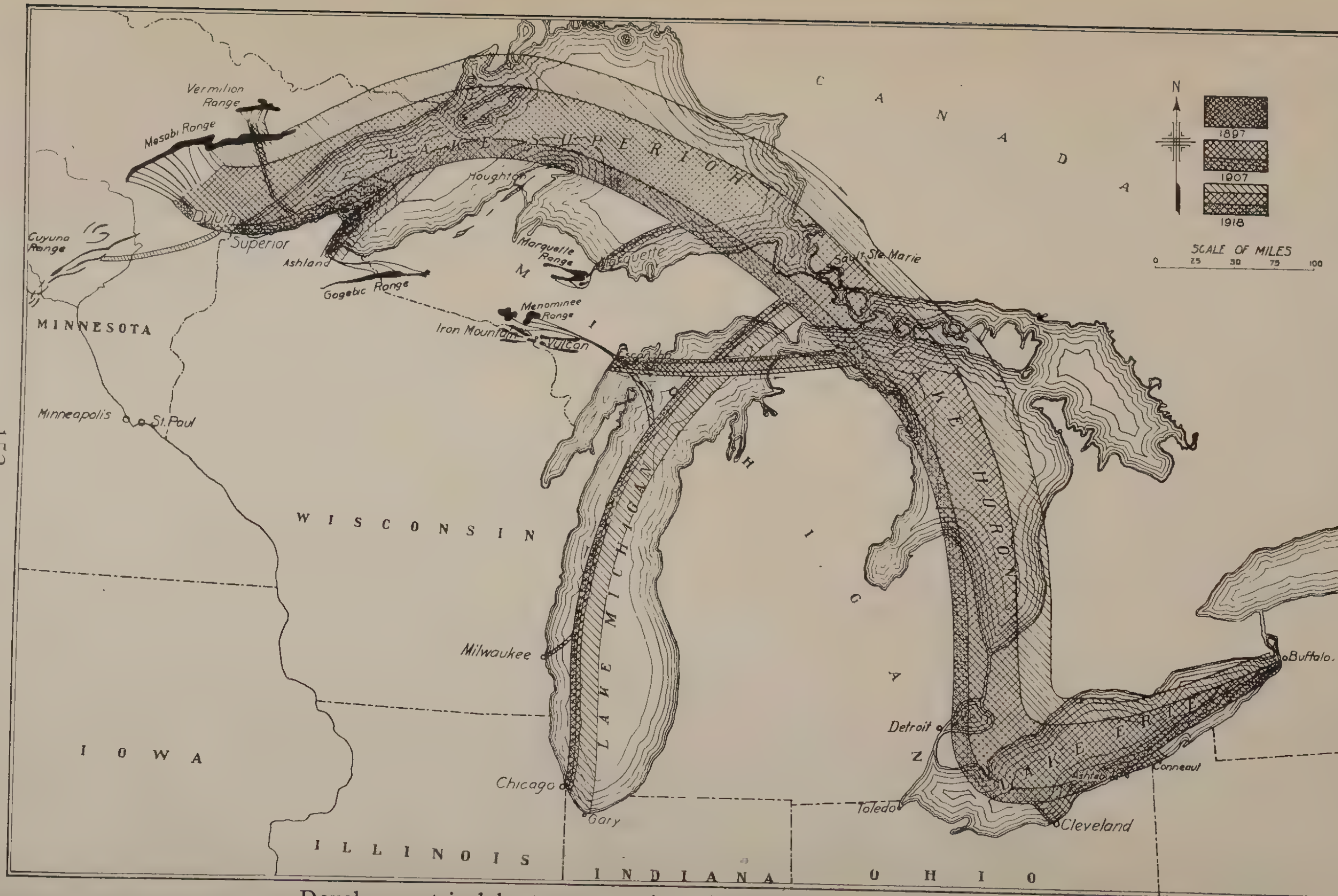
The volume per ton for the iron ores of the region ranges from seven cubic feet for the hard specularite and magnetite ores to about seventeen cubic feet for the soft and porous hematite and limonite ores. The volume, of course, depends on the density of the components, on the pore space and on the moisture. The volume may be readily calculated or determined graphically by methods developed by Mead[1] from the measurement of the three factors just named.

The density or specific gravity of the mineral constituents must be determined for the mineral aggregate rather than for each mineral.

Exploration for iron ore has been carried on by many different methods. The earliest work of this kind consisted merely in the search for outcrops of ore. Later, much test pitting was done where the overburden was shallow, but for many years exploration has been accomplished largely by churn drilling or diamond drilling, following the location of favorable areas by magnetic survey by dip needle and dial compass.

With the lowering of grade of the ores commercially available, due to more favorable market conditions and to improved methods of concentration, the known reserves of iron ore in the

[1]Monograph 52, U. S. G. S., 1911, page 481.



Development in lake transportation of iron ores, 1897, 1907 and 1918

district have increased in large measure; furthermore, the known reserves of iron ores have been increased from year to year by new discoveries which have, in general at least, kept pace with the exhaustion of reserves by mining during the last ten years, in spite of the fact that the tonnage of ores mined has increased rapidly.

Origin. The iron ores of the Lake Superior district have been shown to be of very unusual and complex mode of origin. Their formation consists in its simplest outlines of two steps, (1) chemical precipitation from ocean waters, (2) leaching out of silica. The first step resulted in the formation of ores which for the most part are too low grade to be commercially used, but nevertheless it produced a concentration of iron considerably beyond that ordinarily found in rocks. The second step is responsible in large measure as the immediate process involved in the formation of the ores.

These two processes may be discussed more fully. The iron bearing formations are regarded mainly as chemical sediments, (1) because they consisted originally of iron oxide, silica, ferrous silicate and iron carbonate, all substances known elsewhere to be deposited chemically; (2) because these substances may be precipitated experimentally in the laboratory by simple chemical reagents which were probably present where the iron formation was produced, and (3) because they usually lack fragmental ore particles. It is, however, recognized that fragmental sediments are present in some cases, probably derived from the erosion of earlier iron formations.

The explanation of the formation of chemical sediments of this unusual type in such great abundance is believed to be found in the influence of volcanic activities producing ferruginous basaltic lavas, which were chilled by contact with ocean waters. A large portion of the iron bearing formation was probably derived from these closely associated eruptive rocks, and considerable amounts of iron are believed to have been contributed in hot solutions from the magma to the ocean waters, other parts being derived by reaction of hot igneous rocks with sea waters.

The second step in this process which is directly responsible for the formation of most of the ore consists chiefly in the removal of silica in solution; it is properly called a secondary concentration of the ore. It is evident that layers of iron formation originally rich in ore would require less secondary concentra-

tion than other layers originally poor in iron. In fact, it is believed that in some parts of the Gogebic and Mesabi districts certain layers of iron formation were originally rich enough in iron to be mined as iron ores under specially favorable conditions. The secondary changes have been effected by surface waters for the most part. These changes involve not only removal of silica by leaching, but also oxidation and hydration of the iron minerals and introduction of secondary iron compounds from other parts of the formations. The slump so well exhibited in some of the mines of the Mesabi range is good evidence that the removal of silica in solution has been dominant over all other processes during the secondary concentration.

Transportation. The transportation of Lake Superior ores is now accomplished on a scale unknown heretofore in the world's history. Eight different railroads are concerned in carrying the ore from the iron ranges to the lakes, and several more in handling the ore from the lower lake ports to the iron furnaces. The tremendous tonnage of ore carried in this way from the mines to the furnaces, and the rapid increase in the tonnage, are shown in the graphic map illustrating transportation of ores on the Great Lakes at three dates, namely, 1897, 1907, and 1918. Aside from the great expansion in the volume of tonnage transported, this graphic map brings out the growth of the steel industry at Gary, Ind., and the development of the new Cuyuna district of Minnesota during the period concerned.

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS

ORGANIZED 1871

INCORPORATED 1905

DULUTH ENGINEERS CLUB

ENGINEERS CLUB OF NORTHERN MINNESOTA

ECNM

SECTION TWO

A LITTLE JOURNEY TO DULUTH AND THE MINNESOTA IRON RANGES

ENGINEERS CLUB OF NORTHERN MINNESOTA

President

A. TANCIG - - - - - - Chisholm, Minn.

Vice-President

O. A. SUNDNESS - - - - - Chisholm, Minn.

Secretary-Treasurer

A. E. MARTOIS - - - - - Chisholm, Minn.

Directors

H. J. McINNIS, Virginia, Minn.
W. R. VAN SLYKE, Eveleth, Minn.
W. E. BATES, Chisholm, Minn.
C. J. CALVIN, Hibbing, Minn.

Representative Minnesota Joint Engineering Board

F. A. WILDES - - - - - - Hibbing, Minn.

DULUTH ENGINEERS CLUB

President

COL. F. A. POPE

Vice-Presidents

W. A. CLARK J. L. PICKLES

Secretary

W. H. WOODBURY

Treasurer

A. U. SHIPMAN

Directors

F. A. POPE W. A. CLARK
J. L. PICKLES W. G. SWART
W. H. HOYT J. R. STACK
F. E. DOWNING

Representative Minnesota Joint Engineering Board

W. G. SWART

FOREWORD

This section, entitled "A Little Journey to the Minnesota Iron Ranges and Duluth," carries the compliments of the Engineers Club of Northern Minnesota and the Duluth Engineers Club to their guests, the members of the American Institute of Mining and Metallurgical Engineers, and is dedicated to them.

As there are many points of interest on the ranges and in Duluth which time will prevent members of the Institute from visiting, we have endeavored to present concisely in this booklet information which visiting engineers will want along the way, together with a pictorial story of big things done in a big way.

In no mining center in the world are things done on a larger scale than on the Mesabi range, and the railway and lake transportation systems that make possible the movement of such immense tonnages are the marvels of the transportation world.

It is indeed gratifying to the engineers of the ranges and Duluth to be associated with this great industry, and it is with no little pride that they welcome the American Institute of Mining and Metallurgical Engineers to while away a few days with them.

Of necessity, one thing has been omitted from these pages,—it is something that must be seen and felt. This journey will have been in vain if every visitor does not long remember the lakes, the woods and air of northern Minnesota in the summertime,—the land of whispering leaves and laughing waters. We welcome you to the workshop and the playground of the nation.

Logging crew eating lunch in the open.

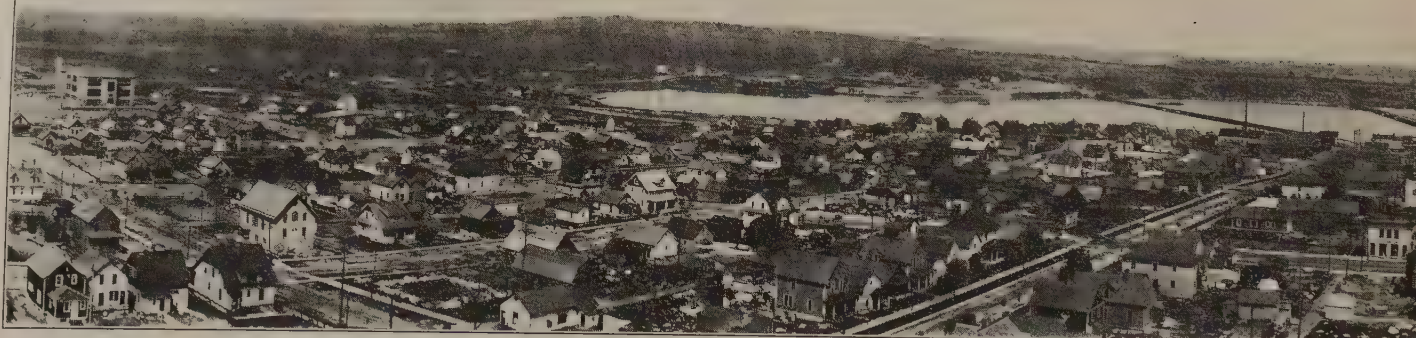
Driving mining timber logs down the Cloquet river.

Scene in Mesabi Park, Hibbing, Minn.

Municipal Recreation Building, Eveleth, Minn. A community center devoted to skating, curling, in the winter, roller skating, dancing, etc., in the summer time.

Municipal Heat and Power Plant, Hibbing, Minn.

St. Louis County Court House, Hibbing, Minn.



Birdseye view of Chisholm, Minn.

Views of Coleraine, Minn.

Headquarters Oliver Iron Mining Company, Virginia, Minn., showing club house, laboratory, office and shops.

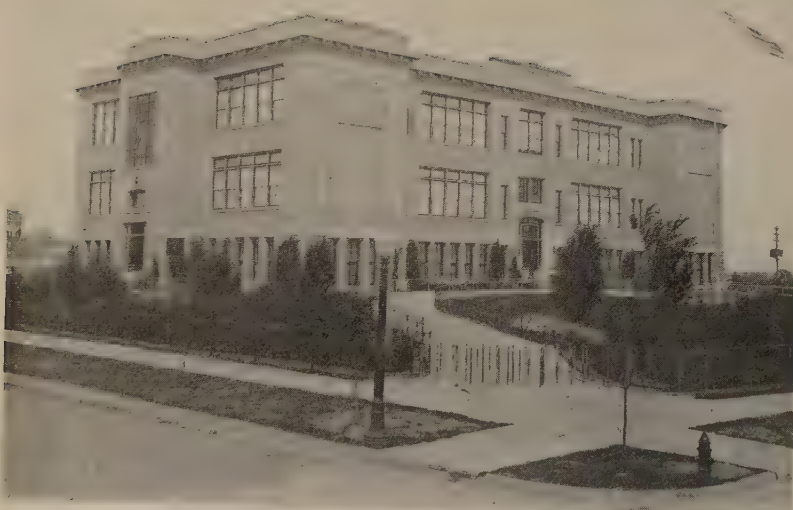
·Headquarters O. I. M. Co., Hibbing, Minn., showing shops, office and laboratory.

Street in Mine Location, Virginia, Minn.

Logging camps on Bass Lake.

Alley in Mine Location, Virginia, Minn., showing garbage collection system.

High School, Chisholm, Minnesota.



Lincoln School, Chisholm, Minnesota.

Mining timber logs being stored on Burntside Lake in the winter.

Monroe Mine Location, Chisholm, Minnesota.

THE IRON RANGES OF MINNESOTA

There are three distinct producing iron ranges in Minnesota, the Vermilion, Mesabi and Cuyuna. In trend the Vermilion and Mesabi are approximately parallel (E.N.E. and W.S.W.) and about fifteen to twenty miles apart. The Vermilion lies farthest north, near the Canadian boundary. It is from seventy-five to eighty miles due north of Duluth. The length of its productive part is about twenty miles.

The Mesabi range is from fifty to seventy-five miles north and northwest of Duluth. Its length along the strike is about 110 miles, and the length of its present productive area about eighty miles. The Cuyuna range lies southwest of Duluth nearly ninety miles, and is the last of the Lake Superior iron ranges to be developed. The relative positions of the ranges are shown on an accompanying map. The Mesabi range is by far the largest producer and contains the largest ore reserves of the three. The Cuyuna is next in quantity of proven ore, and in production since 1916, while the Vermilion is first in average quality of ore.

On the west, both Vermilion and Mesabi ranges disappear beneath heavy glacial drift; and on the east, extend into Canada, the so-called Gunflint range near the international boundary being an eastward continuation of the Mesabi formation. This latter range is of no economic importance, however, at present. The exploration and development of the Cuyuna range has proved up a considerable tonnage of manganiferous iron ore, besides ordinary merchantable iron ore.

In 1852, J. G. Norwood mentioned iron ore at Gunflint Lake, and stated that it appeared to be in the eastward continuation of the hills known farther west as the Mesabi, extending to Pokegama Falls on the Mississippi River. In 1866, H. H. Eames, the first state geologist of Minnesota, described ore on the western end of the range at Prairie River and gave several analyses. Desultory exploration work followed intermittently, but was confined largely to the area west of Birch Lake and to the vicinity of Prairie River. In 1875, Prof. A. H. Chester, from Hamilton College, New York, traveled along the range from Embarrass

Lake eastward toward Birch Lake. In a report of this trip, published in 1884, he called attention to the magnetic character of the iron in the area and to the fact that the alternating iron layers are not thick or continuous. In 1879, N. H. Winchell, state geologist of Minnesota, described the occurrence of iron ore in Range 14 West in the Mesabi district and published analyses. In 1881, he reported a trip from Embarrass Lake to Range 14, and called attention to the magnetic character of the iron bearing formation in Range 14 as well as its similarity to the formation at Gunflint Lake. He urged the state to take steps to have these ores developed.

In the early 80's, Mr. George C. Stone, having succeeded interesting Mr. Charlemagne Tower in the ore deposits on the Vermilion range near the present village of Tower, docks were built at Two Harbors and the Duluth and Iron Range Railroad was built to Tower. The first shipment of ore was made in 1884. In 1886, the whole property, including mines, railroad, docks and land grant, was sold to the Minnesota Iron Company, and later, on the organization of the United States Steel Corporation, became a part of the holdings of that corporation. The first mine to be developed near Ely, twenty-one miles east of Tower, was the Chandler, which began shipping ore in the fall of 1887. Since then the Pioneer, Zenith, Savor, Sibley and Section 30 have been opened in what is known as the Ely district.

On the Mesabi range, ore was discovered in the fall of 1890 near the present Mountain Iron mine, by the Messrs. Merritt of Duluth, and in the fall of the following year on the Biwabik property by the same parties. Since these discoveries the development of this range has been phenomenal. By the end of 1893, three railways, the Duluth and Iron Range, Duluth, Missabe and Northern, and Eastern Railway of Minnesota (Great Northern system), connected the mines with ore docks at Two Harbors, Duluth and Superior.

The first shipment of ore from the Cuyuna range was made in 1911, from the Kennedy mine.

Minnesota furnishes yearly about 65 per cent of the iron ore produced in the United States, the shipments during 1909 amounting to 34,787,913 tons.* The shipments by ranges for 1918 and 1919 were as follows:

*Tons of 2,240 pounds.

	1918	1919	Total Iron Ore Produced to Jan. 1, 1920
Mesabi Range	40,396,711	31,997,699	520,686,631
Vermilion Range	1,192,908	929,049	43,179,510
Cuyuna Range	2,478,800	1,861,165	11,660,147
Total Minnesota	44,068,419	34,787,913	575,526,288
Michigan and Wisconsin Ranges	18,767,753	13,758,738	371,019,629
Total Lake Superior District	62,836,172	48,546,651	946,545,917
Percentage of Total from Minnesota	70%	72%	61%

Loaded in standard steel ore cars of forty-five tons each, the 1919 production would make a train extending from London to New York.

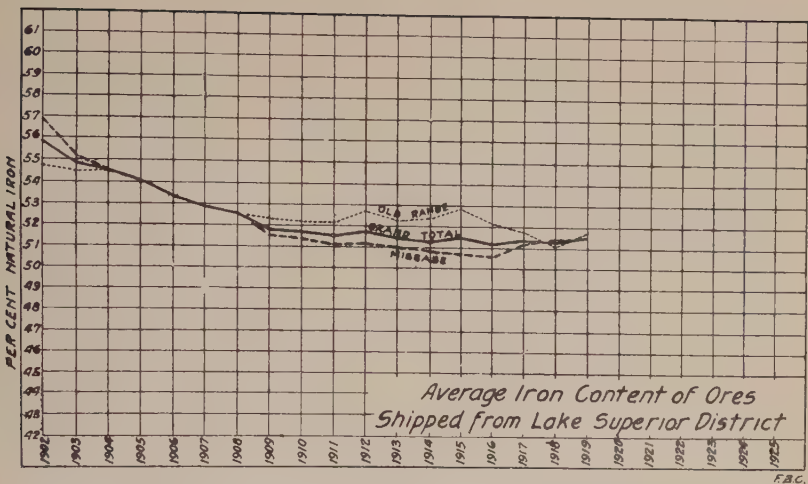
The maximum output was in 1916, when 46,189,000 tons were produced.

QUALITY OF ORE, LAKE SUPERIOR DISTRICT

In recent years, much has been said and written on Lake Superior ores, giving the impression that the quality of the ore is deteriorating in grade and that the reserve of high grade ore is rapidly being depleted. Average analyses of ore produced in this district since 1902 show that the average quality has been practically uniform since 1910, and now closely approximates the average for the total reserves of merchantable ore.

The accompanying tables and charts show the average analyses for the past ten years, weighted according to tonnage:

Year	Tons	Analyses Dried at 212° F. — Iron (Natural)	Phos.	Silica	Mang.	Average Moist.
1919....	46,666,878	51.57	.108	8.04	.73	11.34
1918....	61,972,871	51.29	.104	8.12	.87	11.29
1917....	62,521,465	51.40	.099	8.02	.76	11.57
1916....	65,191,903	51.20	.097	8.00	.73	11.58
1915....	45,883,488	51.49	.100	8.14	.64	11.29
1914....	31,434,096	51.34	.095	8.21	.65	11.30
1913....	47,906,332	51.37	.090	8.03	.66	11.44
1912....	45,863,223	51.69	.096	7.93	.65	11.01
1911....	31,501,183	51.47	.095	8.38	.64	10.93
1910....	42,366,180	51.68	.092	7.97	.66	11.06



The chart above shows graphically the average natural iron content for the old range, Mesabi, and grand total Lake Superior ore shipments since 1902.

During the last ten years the decrease in iron content for shipments from all ranges except the Menominee was only .05 of 1 per cent, while for the Menominee ores there was an increase of .052 of 1 per cent. These tabulations and the chart prove that the average quality of the total annual production of iron ore from the Lake Superior district is uniform. Mining men of the district know that all of the merchantable ores of every ore body are being mined out cleanly, and therefore the present average iron ore content of total annual shipments from the district may be expected to continue as long as the present merchantable ore reserves last. There is no logical reason to expect a decrease in the average iron content. Furnaces require ore of definite quality, and if this quality of ore cannot be produced from the natural ore bodies, it must be produced by mechanical means—that is, by concentration of low grade ores or iron formation.

An enormous quantity of iron formation is available for concentration in the Lake Superior district, but it is incorrect to attempt to show, as some writers have done, just how many millions of tons of ore can be added to the reserves of the district for each 1 per cent decrease in iron content of ores or ore material mined and used below the average now mined. There is only about one ton of so-called low grade non-merchantable ore for every eight tons of merchantable ore in the present natural

ore bodies, and a considerable part of such low grade ore material is so located in the ground as to be unminable with the merchantable ores. Therefore, this material cannot be considered a very large source of future ore supply. When the present supply of natural merchantable ores is insufficient for the demand, undoubtedly the deficit will be supplied from the concentration of parts of the iron formations of the different iron ranges of the Lake Superior district. Developments are under way already, as indicated elsewhere herein, in which the original iron formation is being concentrated into merchantable iron ore.

The figure on page 150 shows graphically the annual shipments from the Lake Superior district since 1902. The broken line shows five year averages, ending with the year plotted, and illustrates the steady increase in production. When this curve will flatten out is problematical, and will depend to a large extent on the beneficiation of low grade ores and concentration of the primary iron bearing formation.

The Taxation of Iron Ore in Minnesota.

Iron ore in Minnesota probably carries a heavier tax burden than any mineral in any other place in the world. The State Tax Commission, created in 1907, originated the system, and with the assistance of the School of Mines is constantly making such adjustments, changes and increases as appear necessary, in order to place mineral reserves on the assessment rolls at their true and full present taxable value. The ore bodies on the Mesabi are so well defined by drilling and underground development that it is possible to estimate very exactly the volume on every forty acres of land taken as a unit. This is done by the operating or holding company and reported annually to the Tax Commission, who check the estimates, having all data, and proceed to fix the valuation for taxation purposes.

The first step is to ascertain a general average selling price in open market, over a period of years; then the total cost per ton (exclusive of royalty) to produce and market the ore. The difference between the average selling price and producing cost per ton is taken as the future full value per ton. This is then discounted at a rate of interest that represents the present and possible future worth of money, over a period of years that will be required to exhaust the ore body, giving the present full value per ton. Iron ore is taxed at 50 per cent of its full value, while other property is taxed at 33⅓ per cent and 25 per cent. To

illustrate, if the average selling value of a good grade of ore is $4.00 per ton at Lake Erie ports, and the production cost, including mining, labor, loading, unloading, lake and rail freight, insurance, brokerage, administration and taxes, is $3.00 per ton, the difference, $1.00, is the future full value. If it will require twenty years to exhaust the ore body, and money is worth 8 per cent, the present value is $0.505 per ton, and 50 per cent thereof, or $0.25 per ton, is the present taxable value.

The Tax Commission has classified the tonnage into two grades, active and reserve tonnage, and these further into six classes, as follows:

Active Mine Tonnage

Class 1—Open pit, low mining cost, high grade ore.
Class 2—Open pit, moderate cost, medium grade.
Class 3—Open pit, high cost, mixed grade ore.
Class 4—Underground, low mining cost, high grade ore.
Class 5—Underground, moderate cost, medium grade.
Class 6—Underground, high cost, mixed grade ore.

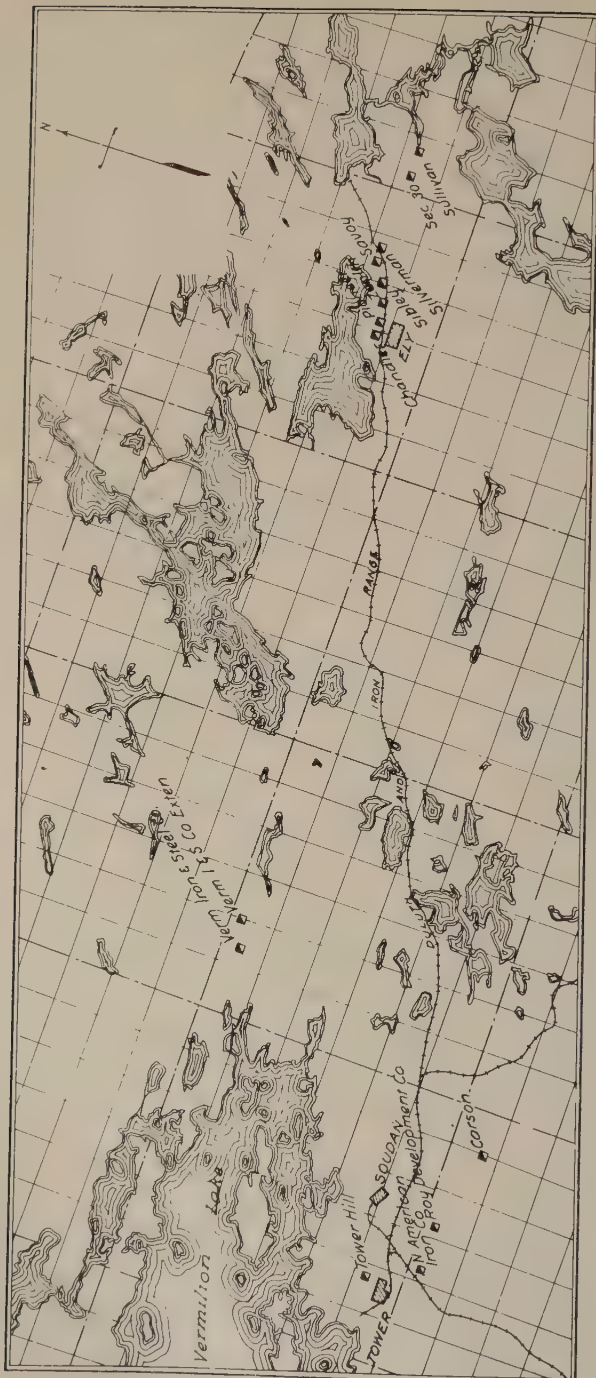
Reserve Tonnage

Classes 1, 2 and 3—Undeveloped reserve ore of active mines.
Class 4—Partially developed and stripped high grade ore.
Class 5—Partially developed, not stripped, medium grade.
Class 6—Partially developed, not stripped, mixed grade.

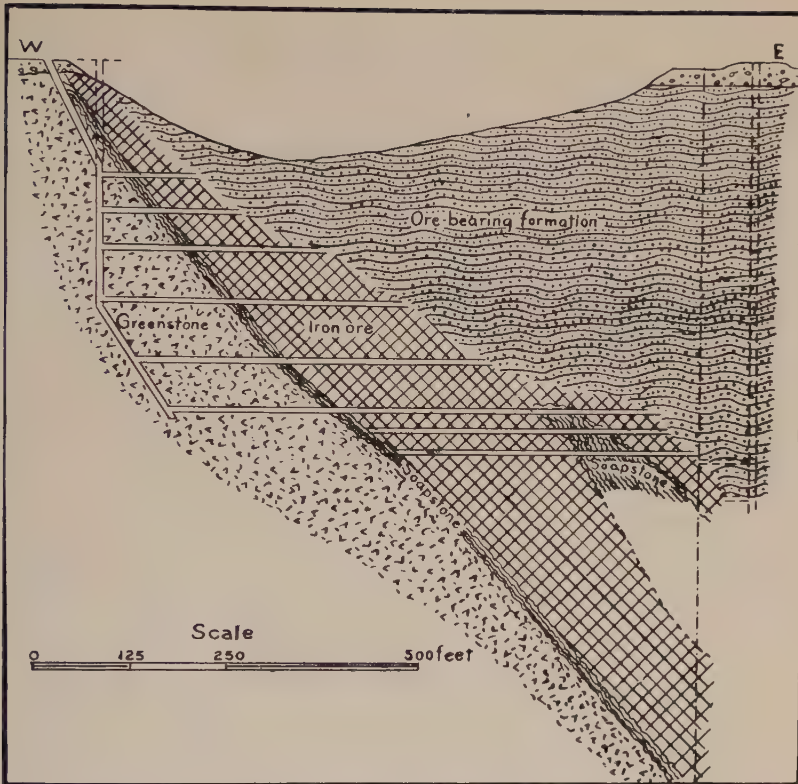
Classified Full and Assessed Value Per ton

	Full Value		Assessed Value	
Class	Active	Reserve	Active	Reserve
1	.764	.486	.382	.243
2	.694	.416	.347	.208
3	.625	.347	.313	.174
4	.532	.254	.266	.127
5	.440	.231	.220	.116
6	.321	.185	.162	.093

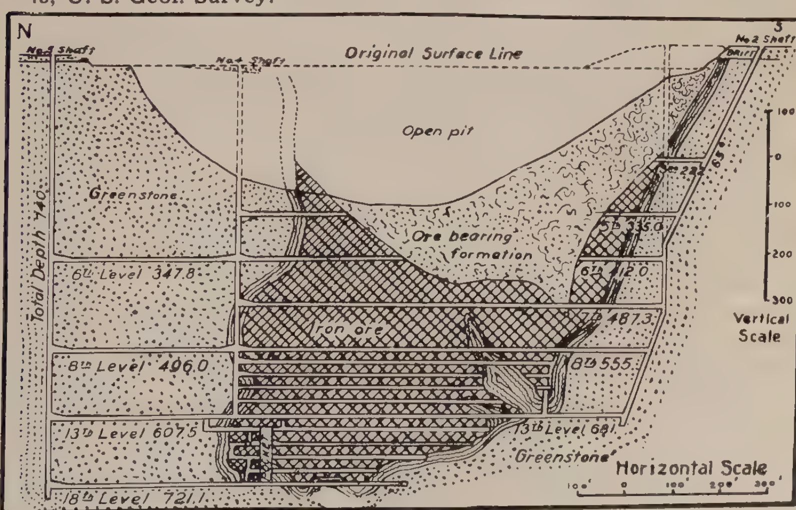
In 1919, the mining interests on the Mesabi and Vermilion ranges paid in taxes $18,000,000, or $0.554 per ton of ore shipped. Several attempts have been made to enact a tonnage or super-tax on all ore shipped, in addition to the ad valorem tax, but have failed, either in the Legislature, or through the veto power of the Governor each time that it was passed by the State Legislature.



Map of Vermilion Iron District showing location of mines.



Vertical east-west section through the Chandler Mine, Vermilion District, showing mode of occurrence of iron ore from Mon. 45, U. S. Geol. Survey.



Vertical north-south section through the Chandler Mine, Vermilion district, showing mode of occurrence of iron ore from Mon. 45, U. S. Geol. Survey.

VERMILION RANGE

The Vermilion range extends from the vicinity of Tower to and beyond the international boundary, crossing into Canada at the eastern end of Hunter's Island. Merchantable bodies of ore have been discovered at but two localities along this extent, at Tower and at Ely, twenty-one miles east.

The iron bearing formation of this range occupies the lowest position geologically of any of the Lake Superior iron formations, being placed by Van Hise and Clements in the Archean, as shown from the following succession:

Lower Huronian	Intrusive granites, granite porphyries, dolerites, and lamprophyres Knife Lake slates Agawa formation (iron-bearing) Ogishke conglomerate
(Unconformity.)	
Archean	Intrusive granites, granite porphyries, and some greenstones Soudan formation (the iron-bearing formation). (Minor unconformity.) Ely greenstone, an ellipsoidally parted basic igneous and largely volcanic rock

The ores of the Vermilion series occur in the Soudan formation (the Agawa iron bearing rocks are not of commercial importance).

At the Minnesota mine at Soudan the ore is a dense, hard hematite, occurring in irregular connected and disconnected lense shaped bodies in the jasper, which is intricately infolded in the ellipsoidal greenstone or green schists, so called on account of a characteristic ellipsoidal parting. The strike is about east and west and the dip approximately vertical, with a westerly pitch. The underground workings at this mine are some 4,500 feet in extent east and west, and over 1,500 feet in depth. The structure here is probably the most complex in the Lake Superior iron districts. Above the iron bearing formation, geologically, comes the basal conglomerate of the Lower Huronian, carrying large boulders and masses of the iron bearing rocks.

The ores at Ely differ from the preceding, mainly in their physical structure, being much more broken and friable. The area in which they lie is a closed trough or syncline, about two miles in length east and west and some 1,500 feet in width. The general dip is nearly vertical, and the pitch of the ore bodies

·Soudan Mine near Tower, where ore was first mined in Minnesota.

"A" Shaft, Pioneer Mine, Ely, Minn.

Underground in Zenith Mine, Ely, Minn.

Long Lake near Ely, Minn.

at the west end of the trough is to the east, while the pitch of those at the east end is to the west. The iron formation here, as at the Minnesota mine, lies in a trough of the older ellipsoidal greenstone, but the folding is not so close. The geological succession is the same as above given. Intrusive masses and dikes of granitic porphyry and basic eruptives cut the whole series, and are found associated with the ore bodies. The ore occurs at the base of the iron formation, just above the greenstone, and has been derived from the jasper or iron formation by ground waters leaching the silica out of the jasper, leaving in place as concentrated ore the iron oxide of the iron formation. The unaltered jasper, therefore, forms a capping or hanging wall of the ore bodies proper.

MESABI RANGE.

The Mesabi range extends continuously from near Grand Rapids, on the Mississippi River, E.N.E. for a distance of about 112 miles to near Birch Lake, where it is covered by the large gabbro flow which forms the base of the Keweenawan series. The same formation (Mesabi) appears again near Gunflint Lake on the international boundary, and shows as far east as Thunder Bay on the north shore of Lake Superior. Between Mesabi station, on the Duluth and Iron Range Railway, and Birch Lake, although considerable exploration work has been done, there is no evidence of concentration of ore in workable bodies. The Gunflint beds are thin alternating layers of chert and hematite. All the workable deposits at present known, on the Mesabi, lie between Mesabi station and Grand Rapids, the greater number being in St. Louis County.

A simplified geologic column is given herewith instead of the complete correlation table given by the United States Geological survey.

Quaternary System Pleistocene Series Unconformity	Glacial Drift 0 to 300 ft.
Cretaceous System Unconformity	Conglomerate and shale 0 to 50 ft.
Algonkian System Keweenawan Series	Duluth Gabbro and diabase dikes and sills (East end of Range)
Unconformity Up'r Huronian Series (Sedimentary)	Virginia slate 0 ft. to great thickness Iron formation 475 to 775 ft. Pokegama quartzite 50-150 ft.
Unconformity Algonkian System Archean System	Basement complex of slate-graywacke-conglomerate series, granites, greenstones, green schists and porphyries.

The north edge of the Mesabi range was easily determined as exposures of the older rocks are fairly numerous; the south edge, or more properly the north edge of the overlying Virginia black slates, was determined by drill work entirely, as there are no exposures of this slate.

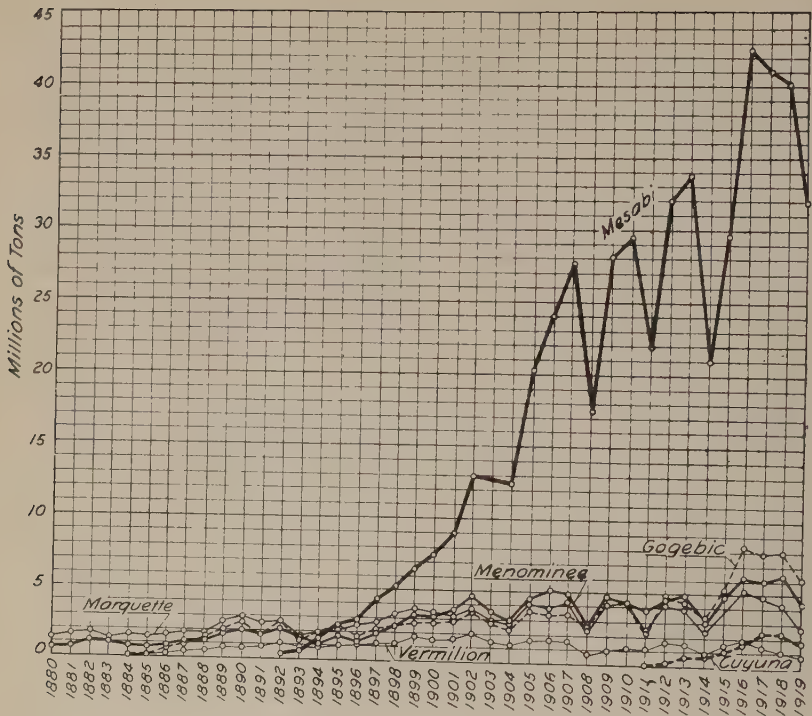
The iron formation is flat-lying with a slight average dip to the south, although local high dips occur. In this respect it differs from all other districts in the Lake Superior region.

The great bulk of the iron formation is ferruginous chert, locally known as taconite. The original rock consisted principally of irregular layers, bands and fine grains of iron oxide (both magnetite and hematite), interlayered with and imbedded in chert layers. A minor amount of iron silicate called greenalite, of amphibole minerals and of siderite, occurs also. In color the rock is gray, red, yellow, brown or green, according to the amount of alteration it has undergone. It is analogous to the jaspers of the other iron ranges. Several slate layers occur in certain horizons of the iron formation, but they are relatively thin.

The ore bodies have been derived from the iron formation by ground waters which leached the silica out of it and left in place the iron oxides and oxidized ferrous minerals of the original rock. This occurred locally at the outcrop of the formation wherever it was sufficiently cracked up by warping to allow meteoric waters and other weathering agencies to enter it. The ore bodies therefore are the result of local weathering of the upturned and exposed edges of the iron formation. They lie in the rock basins or troughs of the iron formation from which they have been derived.

It may be said that in general their longer axes are parallel to the strike of the formation, although they are exceedingly irregular in outline. The transition between the rich ore and the taconite* (local term for the ferruginous chert of the ore formation) is usually very abrupt, and the original bedding can be distinguished plainly running through the ore. The Hull-Rust-Mahoning orebody and its extensions are known to have a con-

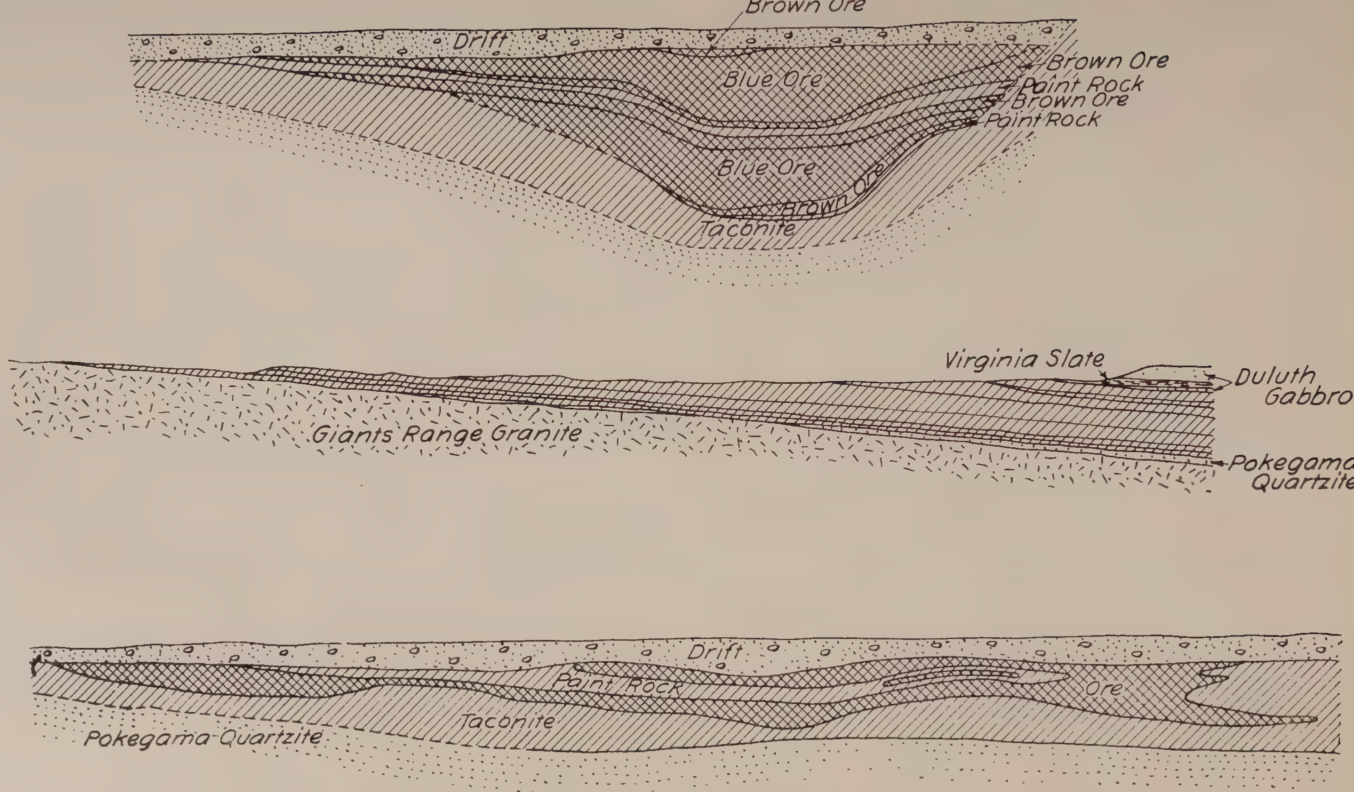
*Named by H. V. Winchell in 1892 from the resemblance to cherty rocks of the same age in the Taconic range of New England.



Production of Iron Ore from the Mesabi Range compared with the production from other Lake Superior Ranges, 1880-1919.

tinuous length of over four miles and an average width of about one-half mile and to be several hundred feet thick in places. These flat-lying ore bodies vary in thickness from a few feet to over 300 feet, are from a few acres to several hundred acres in area, and a large majority occur just beneath the glacial drift, although some have a taconite or slate capping. The surface or overburden varies from practically nothing to some 200 feet; perhaps an average would be between 60 and 80 feet.

The ores of the Mesabi are dark red, brown and yellow hematites and limonites, more or less hydrated, and are secondary replacements or enrichments of the taconite. In physical structure they vary from a fairly coarse ore to earthy or powdery phases, and are comparatively high in moisture. At the west end of the range the ores are more or less "sandy," a condition evidently resulting from the incomplete decomposition of the cherty layers in the banded cherty iron formation.



Mesabi Range—Top Section: North and south section of an ore deposit near Hibbing, showing slump of an ore body due to leaching of silica, Mon. 52, U. S. G. S.

Center Section: North and south geological section through the Mesabi Range, Mon. 52, U. S. G. S.

Lower Section: North and south section through the Mesabi Range showing detailed structure of ore deposits, Bull. No. 17, Minn. Geol. Survey.

Since the Mesabi range was opened there have been removed 354,301,371 cubic yards of stripping. Nine million cubic yards of lean ore have been put in stockpile by the Oliver Iron Mining Company alone. Compare these figures with the total excavation for the Panama Canal to date, which is 232,351,000 cubic yards.

The total stripping and lean ore excavated to date on the Mesabi range would make 363 city blocks 300 feet high. There are 125 active producing mines on the Mesabi range, and a total known ore reserve of 1,400,000,000 tons.
logical Survey.

The deepest stripping to date has been done in the Buffalo and Susquehanna pit, where a depth of 156 feet of overburden was removed in one place and an average of 135 feet over a considerable area.

THE CUYUNA RANGE.

This range lies in Crow Wing, Aitkin and Morrison counties, in north central Minnesota.

Mr. Cuyler Adams' attention was drawn to the magnetic variations in that vicinity, and after detailed magnetic work he started drilling near Deerwood, in 1903, and it was demonstrated that an iron formation existed in that vicinity.

The country is flat with few topographic features or outcrops to indicate the presence of iron ore. The iron formation has been located in two separate areas, known as the North and South ranges.

The North range extends from the vicinity of Crosby and Ironton westward and northward to the Mississippi river and contains practically all of the producing mines of the district. The South range extends from Deerwood, or a few miles east of there, southwest through Brainerd and has been traced by magnetic surveys and drilling a considerable distance into Morrison county. No mines are being operated on this range at the present time. Extensions of both ranges have been traced eastward to the vicinity of and beyond Aitkin.

Drilling done prior to 1918, north of Crosby, indicated the probable continuation of the Western Mesabi range iron formation southward into the Cuyuna district. Careful examination of the ores and rocks of the producing mines of the North range

and classifications of drill cores in 1918, proved that the iron formation of the Cuyuna and Mesabi ranges is the same in character and geologic age. Previously some geologists had thought that the Cuyuna range iron formation might be younger in age than that of the Mesabi range. Four similar major horizons or subdivisions can be recognized on both ranges and on both there is a quartzite (Pokegama) at the base of the iron formation and a gray and black slate (Virginia) overlying it. Intraformational conglomerates occur in the iron formation in corresponding horizons on both ranges. The typical taconite or ferruginous chert of the Mesabi range is very prominent on the Cuyuna also, but the rocks of the latter contain more cherty iron carbonate than do those of the former.

On the Cuyuna range the iron formation has been folded into a series of parallel and very close synclines and anticlines having a northeast-southwest strike and southeastward dip. The main pitch of the folds is to the northeast but cross folding gives local pitches to the southwest. Where the tops of the folds have been eroded, the iron formation has been subject to weathering and leaching by ground waters and such concentrating agencies have formed ore bodies in the richer horizons or layers of the iron formation. As is to be expected, such ore bodies occur in the upper portions of the steeply dipping iron formation, have considerable length along the strike and are comparatively narrow across the bedding. They are tabular or lenticular in shape, therefore, and appear to overlap one another because of the fact that they are concentrated from different layers or horizons of the iron formation. Some of them occupy the entire basins of the more closely folded synclines.

Very rich concentration has been found in drilling to a depth of 800 feet but most of the merchantable ore bodies probably do not continue to such a depth. The quality of iron ore being produced from the Cuyuna range compares favorably with that of the Mesabi range, the average probably being a little lower than the shipments from the latter range.

In the North range several ore bodies have been explored and developed which contain considerable tonnages of manganiferous iron ore, having manganese contents from 2 per cent to 25 per cent dry manganese. These ores occur in two particular horizons in the iron formation, and similar ores, though of lower average managanese content, occur locally in corresponding horizons in some Mesabi range ore bodies. Although these

manganiferous ores from the Cuyuna range received particular attention during the war, the tonnage of them developed to date is only one-sixth or one-seventh that of the merchantable iron ores. Therefore the future and permanence of the district is dependent almost entirely on its straight iron ores rather than on the use of its manganiferous ores.

Glacial drift consisting principally of sand and gravel covers the district, varying in thickness from sixty feet to several hundred feet.

Prior to the late war practically all of our supply of ferro-manganese was imported or manufactured from imported ores. The commandeering of ships by the United States decreased materially this supply and forced the steel companies and government experts to devise some way of meeting an unusually heavy demand for steel products by the use of greater quantities of alloys which could be made from domestic ores.

As a result, considerable attention was directed, by steel makers, toward the adoption of modified metallurgical practices which would permit the greater use of manganiferous ores similar to those of the Cuyuna range.

This class of material may be used for the manufacture of spiegel or for increasing the manganese content of basic pig

Armour Mine No. 1, Cuyuna Range.

iron. Formerly spiegel was used in connection with the bessemer process wherever the carbon content of steel permitted. Phosphorus for such spiegel was required to be under 0.10 per cent. It has been found possible from a practical standpoint to use spiegel satisfactorily in connection with the open hearth steel making process, in which case a higher phosphorus content is permissible.

Manganiferous ores too low in manganese or too high in phosphorous to produce satisfactory spiegel may be used in the manufacture of basic pig iron, which fact has increased the demand for ore of this character, and inferior grades of manganiferous ore are made to serve the purpose for which formerly high grade manganese ores were required. The future market for Cuyuna range manganiferous ores depends on whether or not the modified metallurgical practices adopted as a war emergency will be continued by steel makers. The two or three principal producers of these ores have established permanent and increasing markets for them among the furnaces. At the present time thirty-seven mines have been developed on the Cuyuna range.

MINING THE LAKE SUPERIOR ORES.

Prospecting and Exploration. Since the Lake Superior ores occur in pockets or distinct bodies and vary much as to character and location, the actual mining of the ores is preceded by much work of an exploratory character. This work includes prospecting and exploration.

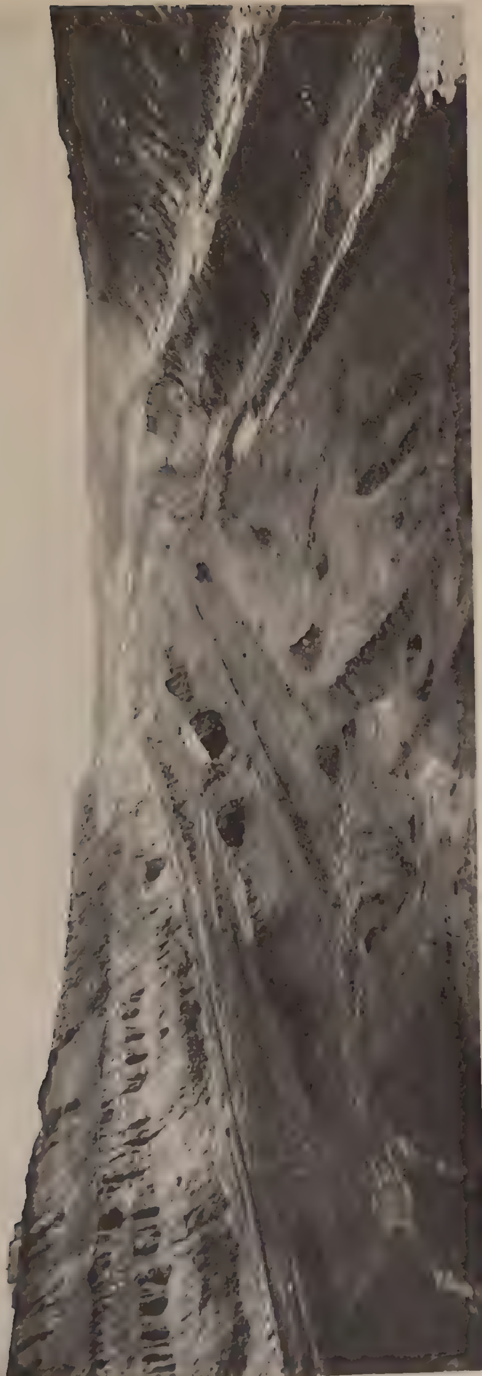
Prospecting is the term generally applied to the quest for surface indications of ore, or the conditions which would warrant the expectation of finding ore in the vicinity. It includes such operations as geological examination, dip needle work, shallow test-pitting, and trenching. The ore bodies of the Mesabi range are non-magnetic, and dip needle prospecting is therefore valueless. On the Cuyuna range, however, magnetic attraction as evidenced by the dip needle has been extensively employed as a guide to the location of ore deposits; in other localities it has found limited application.

Drill Exploration. After the presence of an ore deposit is known or suspected, resort is generally had to exploration by means of diamond or churn drills. On the old ranges geological conditions generally make this manner of ascertaining the exact limits of an ore deposit impracticable; so, if two or three adjacent drill holes develop considerable depths of ore, the sinking of a

shaft for underground exploration, development and mining is generally considered warranted. On the Mesabi range, however, the flat-lying and comparatively shallow characteristics of the ore formation warrant much more extensive drill explorations. On this range, then, an ore body is almost invariably followed out with the drills, and its limits are determined to the point where the complete plan of development can be worked out in advance of actual mining operations.

Methods of Mining. Both open pit and underground methods of mining are employed in the Minnesota mines of the Lake Superior district. On the Mesabi range the ore bodies are, as a rule, flat-lying with relatively large areas of outcrop, and open pit mining is, therefore, general. Of course, there are many deposits on this range that, on account of limited operating area, excessive depth of over-burden, or for other reasons, must be mined by underground methods, and there are, therefore, a large number of underground mines also. But by far the greater part of the tonnage produced from the Mesabi range comes from open pits.

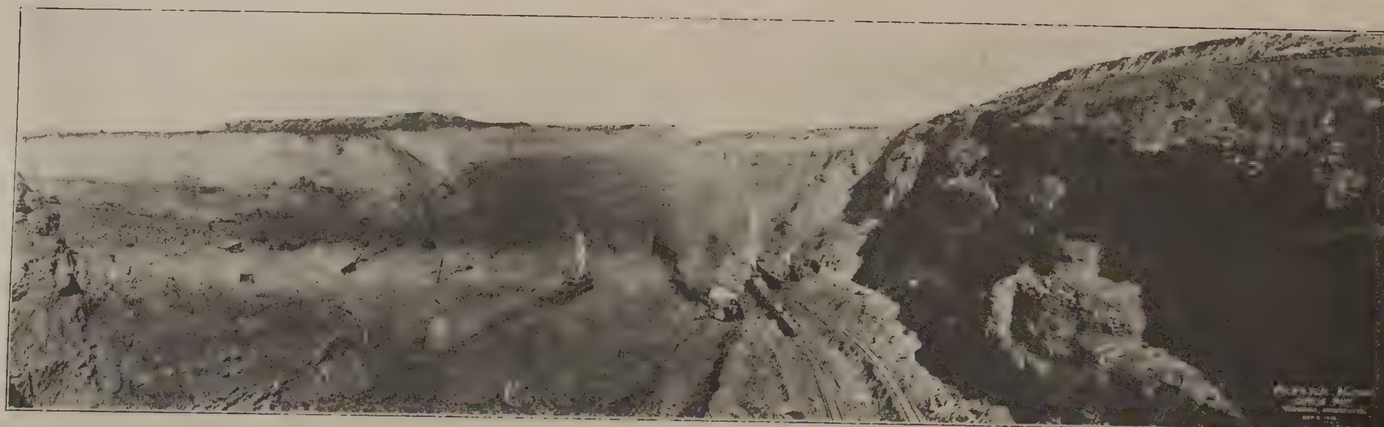
Open Pit Mining. Before deciding whether an ore body should be mined by underground methods or as an open pit, a detailed operating-analysis is made of the proposition to determine by which method the ore can be mined most economically. Estimates are made determining the yardage of overburden, or "stripping," that must be removed to uncover the ore body; the tonnage of ore which can then be mixed by steam shovel and the additional tonnage which can be "scrammed" or "milled" in the pit after the limits of steam shovel operation have been reached. Then the cost of the entire operation, including interest charges on the necessarily large investment in stripping removal, is calculated and reduced to a final cost per ton of ore recoverable. If this figure is less than the probable cost per ton of underground mining, and if the other operating conditions are satisfactory, open pit operation is deemed advisable. The laying out of an open pit mine involves the following engineering problems: First, outlining the area of ore which it will pay to strip, i. e., considering the two factors of depth of ore and thickness of overburden; second, planning the disposal of stripping which it will be necessary to remove to uncover the ore body, for this material must often be hauled considerable distances from the pits to dump grounds; third, locating the track systems outside



Dunwoody Mine, Chisholm, Minnesota.

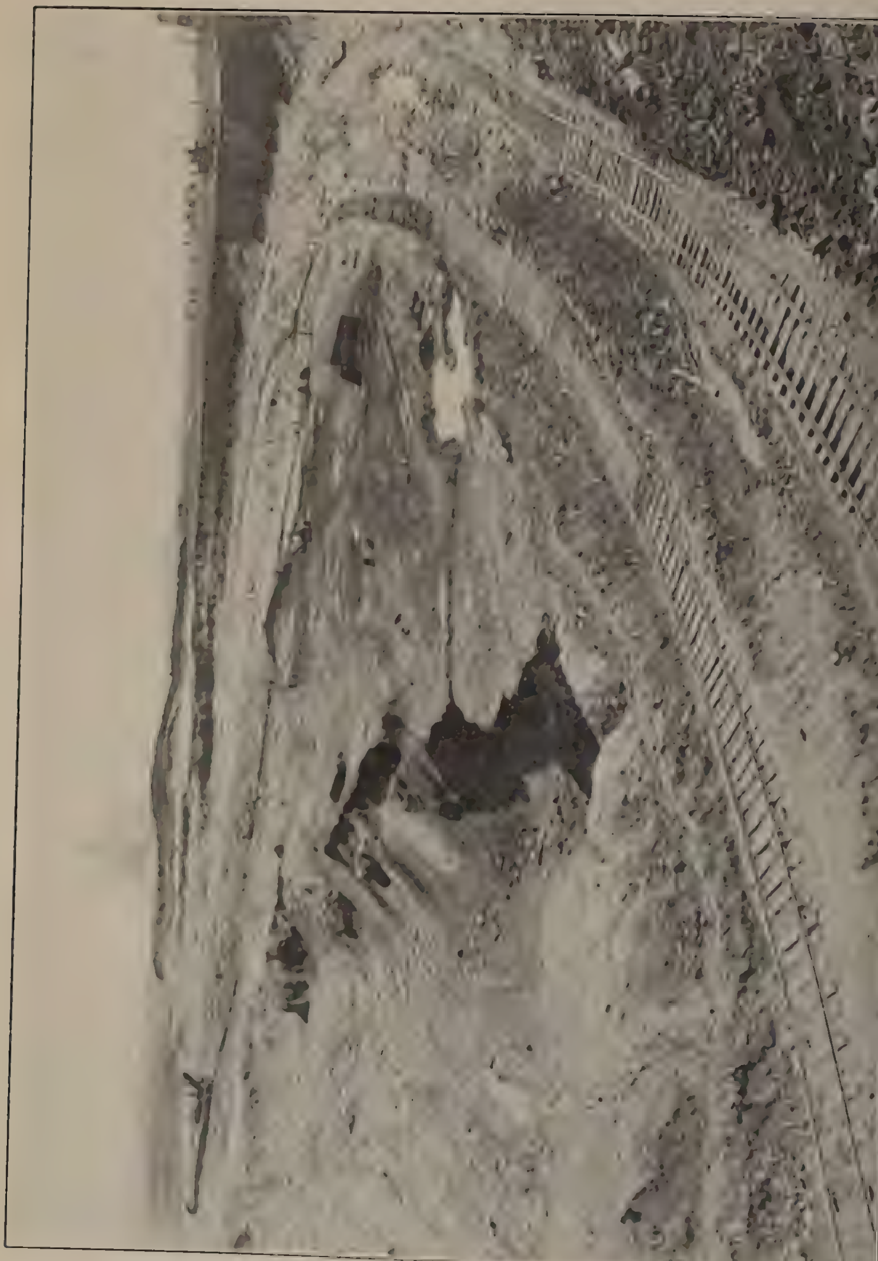
Mahoning Mine, Hibbing, Minnesota. Total shipments, 29,618,759 tons.

Shenango open pit mine, Chisholm, Minn. Total shipments 5,635,000 tons.



Alpena Mine, Virginia, Minn. An open pit mine approaching the end of steam shovel stage.

Fayal Open Pit. Eveleth, Minn.



the pit for the transportation of stripping and the hauling of ore; fourth, designing the system of railroad tracks within the pit that will make available the maximum quantity of ore accessible by steam shovel, which designing generally involves a series of switchbacks on limiting operative grades and curvature; fifth, providing for drainage of the pit; and, sixth, planning in advance for the mining of the ore that cannot be mined by steam shovel. The general term open pit mining covers three recognized methods of mining, i. e., steam shovel, milling and scramming. Steam shovel mining needs no description; it is simply the loading of ore directly into railroad cars by steam shovel.

Milling is a term applied to a thoroughly well worked out system of open pit mining, extensively prosecuted in the early days and still applied under suitable conditions. It consists of the following operations: First, the removal of the overburden from the ore body to be mined, this being done by steam shovel; second, the sinking of a hoisting shaft or incline to the bottom of the ore and the development of a system of underground tramming drifts tributary to the shaft and underneath the ore to be mined; third, the putting up of a number of raises (vertical openings) extending from the underground drifts through the ore; fourth, "milling" or shoveling the ore into the raises, through which it is drawn into tram cars operating in haulage drifts that lead to the shaft or incline, where it is hoisted to the surface. The milling system of mining can be well applied to small ore bodies which can be successfully stripped, but where the open pit areas are too small to permit of steam shovel operation; also, as a sequel to steam shovel mining in larger pits where considerable depths of ore remain after the limits of steam shovel work have been reached.

Scramming is a term applied colloquially on the Mesabi range to the operation of recovering shallow pockets and hummocks of ore left unmined in and around the open pits following the period of steam shovel mining. It is a general term inclusive of hand work, scraper work, mining with dragline excavators, etc., and is applicable generally to the operation of "cleaning up" a pit after its period of real production has passed.

Advantages of Open Pit Mining. It is very apparent that open pit mining, when feasible, offers decided advantages as compared with underground methods. Probably the most evident of these is the possibility of big production; in 1916 the Hull Rust mine alone shipped 7,665,611 tons of ore—more than 10 per cent

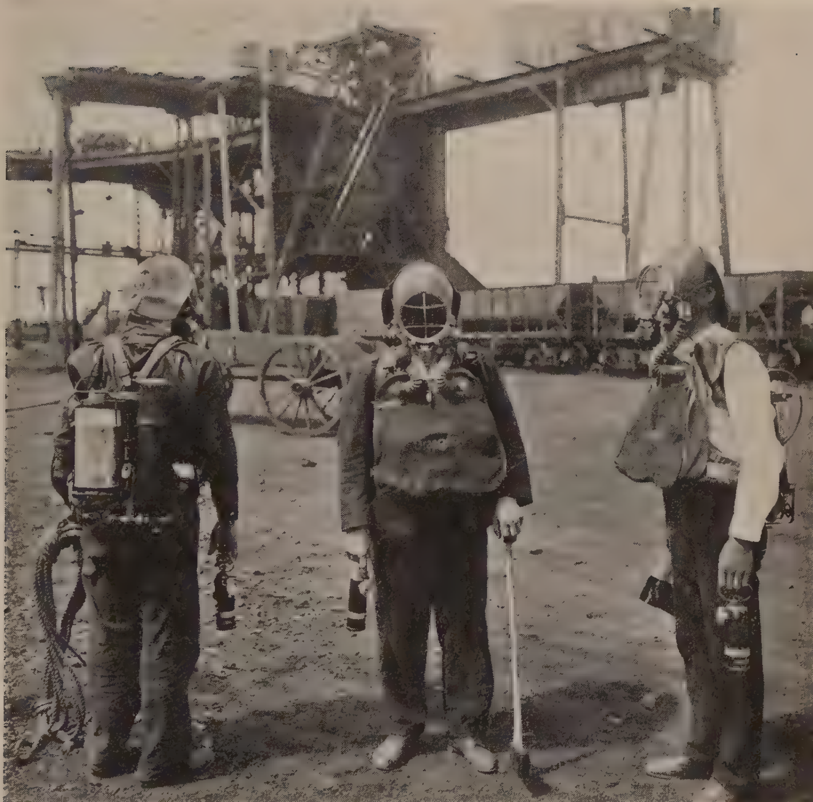
Hull Rust Mine, Hibbing, Minn.

Glen-Leonard Mine, Chisholm, Minnesota.

of the total mined in the United States during that year, which, according to the U. S. Geological Survey, amounted to 75,167,672 tons. Where the overburden is light in comparison with the depth of ore, and stripping charges are not heavy, open pit mining produces low cost ore. It accomplishes a great saving in labor; the output per man per day from the open pit mine is many times that from the average underground mine. Aside from the skilled operators of the steam shovels and locomotives, common labor only is required in open pit mining, while in underground work the miner is a rather high class workman, and receives a relatively high wage. Owing to this latter condition, strikes have never been able to interfere seriously, so far, with the output of Mesabi range open pit mines.

Underground Mining—Slicing. The system of underground mining most generally in use in the mines of the Mesabi range is known as top-slicing and caving. The development of a mine under this method is as follows: First, a shaft is sunk to the bottom of the ore body, or to such depth in the ore as has been determined as desirable. Second, after cutting a "station," pump-room and pocket at the bottom of the shaft, a main haulage drift, or system of haulage drifts, is driven out underneath the ore body. Third, raises are put up from the haulage drifts at inter-

Interview view of Bray Mine Change House, Keewatin, Minn.



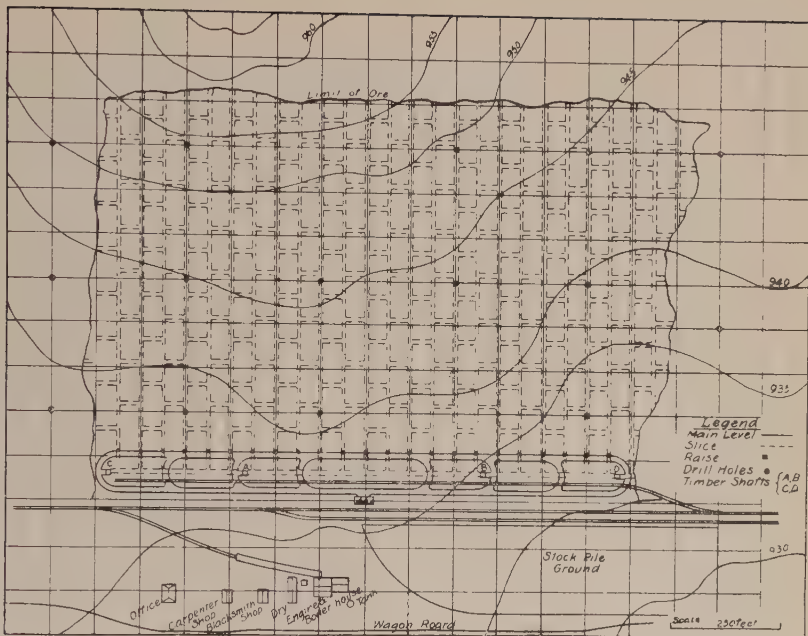
Draeger oxygen apparatus. Used in case of fire or bad air in mine rescue work.

vals of about fifty feet along the drifts through the ore body to the top of the ore. Fourth, cross cuts are driven from the tops of the raises to the limits of the ore body or the property lines, the cross cuts being parallel and the same distance apart as the raises. Fifth, beginning at the ends of the cross cuts farthest from the raises, the ore is "sliced" out between cross cuts, trammed to the raises, dumped into the latter, drawn off through chutes into cars operating on the main haulage level, hauled to the shaft, dumped into the shaft pocket and hoisted to the surface, where it is either loaded direct into railroad ore cars, or (if in the winter time) stockpiled for later shipment. A "slice" consists of a room opened up between crosscuts, and may be one, two or more sets wide depending on the tendency of the overburden to crush the temporary timber supports. When the ore

·Shelter houses to protect workmen from flying material hurled by blasting in the open pits.

has been removed from the room or slice, the supporting timbers are blasted out and the overburden allowed to cave and fill it. Before blasting the timbers, however, boards are laid over the floor and nailed over the exposed ore faces of the room to prevent admixture of the caved material with the ore in place. While slicing and caving operations are proceeding on the top level, the cross cuts to develop the level immediately below are being driven, and as soon as considerable areas of cave have been developed on the first level, slicing under these areas is started on the second level. Thus, the entire ore body is mined, slice by slice, and level by level. Levels are generally about eleven feet apart, floor to floor. Haulage of ore on main levels from chutes to shaft may be by hand, mule or electric motor, depending on the size of the mine. On the sub-levels the ore is hand-trammed in small dump cars, or for short hauls, in wheelbarrows, from the slices to the raises.

Advantages of the Slicing System of Mining. The top-slicing-and-caving system has many advantages. It gives a high percentage of ore extraction. If desired, the ore from different working places can be separated, and two or more grades can be produced from the same mine. Development and mining



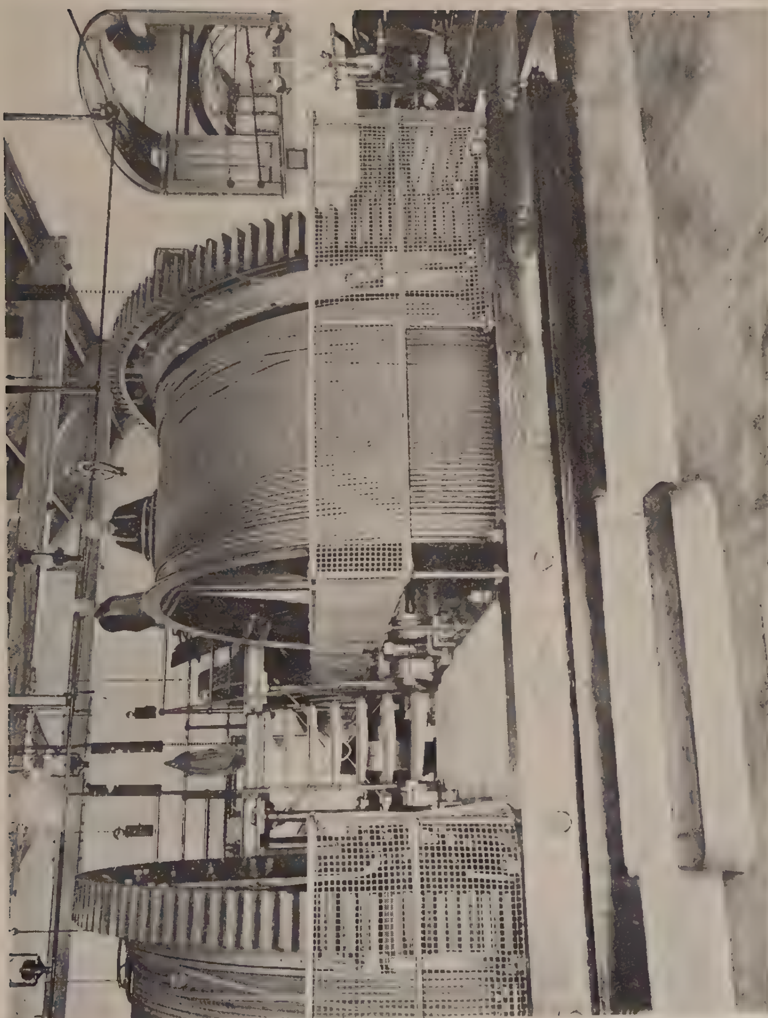
Typical Development for Top Slicing Method, Mesabi Range.

operations are simple and safe, and can be carried out along well defined plans worked out in advance. While the consumption of mining timber is high, cheap inferior grades are used, and under ordinary conditions this item of cost is not excessive. In common with most other systems of mining, it possesses the disadvantage of a limited number of working places; considerable handling of the ore is also necessary.

The depth of mine shafts on the Mesabi range rarely exceeds 350 feet. The average is probably between 250 and 300 feet. On the old ranges, where the rock formations have been folded and tilted, mining operations extend much deeper, and mine shafts 500 to 1,500 feet deep are common, while in some cases mining operations are still in ore at depths well in excess of 2,000 feet.

Grading the Ores. In the early days of iron ore mining, no grading of the ore from analysis, such as prevails today, was made, and the ore was known by the name of the mine that produced it. Then, the number of mines was small, and the ore from any one mine was fairly uniform. As the production increased, however, and the field of available ore was broadened to include deposits previously regarded as unmerchantable, it

Republic Iron & Steel Co. Schley Mine, Gilbert, Minn.



Mine Hoist. Two men are always stationed on platform when men are hoisted or lowered.

Surface Plant, Philbin Mine, Hibbing, Minn.

Pickands-Mather & Co.'s Elba & Corsica Mine, McKinley, Minn.

Standard Steel Headframe and Stockpile trestle, Mesabi Range.

became necessary, in order to simplify shipping, to grade ores according to their composition, and, further, to mix ores differing in composition to produce certain grades. Finally, it became quite common for one mine to ship several different grades, and for the ore from several mines to be grouped under one name. These conditions brought about a necessity for exact knowledge of the composition of the various ores, and whether or not, in the case of mixed ore, each cargo was of the grade guaranteed. This grading is done by sampling the ore in the cars as fast as they are loaded at the mine, in lots not exceeding ten, and making a rapid but accurate analysis for the determining elements. From this analysis the class or grade of the ore is fixed, and its allotment into a certain group can be made. This is the work of the grader, who, from the analysis of the cars as submitted to him, makes a theoretical shipment in which the contents in silica, iron, phosphorus and possibly manganese, the determining factors in the value of an ore for its particular purpose, must fall within certain predetermined limits.

Transporting the Ores. The Lake Superior ores now supply all the furnaces in western New York, western Pennsylvania, Ohio, Illinois, and Indiana, as well as those in the ore producing states of Michigan, Wisconsin and Minnesota. In order to reach these markets, the ores must be transported for distances varying from 300 to more than 1,000 miles, depending upon the locations of both the mine and the furnaces. The cost of transporting this ore by rail alone would be a serious handicap to some furnaces, but fortunately the chain of great lakes affords a cheap mode of transportation for the greater part of the long as well as the short distances. Nearly all the ore mined in the ranges, then, goes first by rail to a harbor on Lake Michigan or Lake Superior, where it is loaded on ore carrying boats that carry it either down Lake Michigan to Chicago or Gary or through Lake Huron and Lake Erie to ports further south. For most of the ore, even these lower lake ports are not ultimate destinations, and another haul by rail is required to place it at the furnace.

Mining and Grading in Winter. In winter the procedure as outlined above has to be changed somewhat. During a part of November, and all of the winter months of December, January, February and March, the ore cannot be transported over the lakes. On this account, operations in the open pit mines of the

Mesabi district are suspended in winter; but in all the underground works, both of the old ranges and the Mesabi, mining is continuous throughout the year, and the ore mined during the non-shipping season must be stockpiled. As this ore is removed it is carefully sampled, and average samples are analyzed daily. These analyses, supplemented by those made in the work of exploration that is constantly carried on in advance of the mining, make it possible to calculate the average composition of each stock pile at the beginning of the shipping season in the spring. This stock, therefore, may be combined, if necessary, with the ore direct from the mines to make up cargoes of definite and known composition.

EVOLUTION OF MINING EQUIPMENT.

The early mining of iron ore in Minnesota was carried on with the most primitive kind of tools. The pioneers used only such equipment as could be packed from Duluth through one hundred miles of forest to the first mines on the Vermilion Range and the operations were carried on with picks, shovels, hand drills and wheelbarrows, the ore being hoisted in buckets with a horse winch and carted in horse drawn wagons to the stockpile. This was about the extent of the mechanical equipment of the Minnesota iron mines in the early eighties.

As soon as a railroad was pushed through from Two Harbors to the Vermilion Range the equipment began to be improved upon; wood burning steam boilers were installed and small steam puffers displaced the horse-winches, wheelbarrows were abandoned and small cars were introduced. Hauling the hoisted ore in wagons was discontinued and trestles were built so that the ore could be stockpiled more cheaply through the use of cars and high piles. These same stockpiles were loaded by hand into the 10 and 15 ton capacity railroad ore cars.

Within a few years a marked change took place—the hand drill gave place to the air drill, such as No. 3 Rands, Ingersolls, Sargents and some Sullivans. Tramming was done by mules, the ore hoisted in self-dumping skips, hoisting engines were introduced and it seemed as though mining as a business in Minnesota had come to stay. At this stage someone conceived the idea of making the stockpile floor about three feet above the top of the ore cars to facilitate the hand loading of stockpile ore for transportation. This was done through the use of wheelbarrows

at first and later by using 1-ton cars running on tracks laid on the stockpile floor.

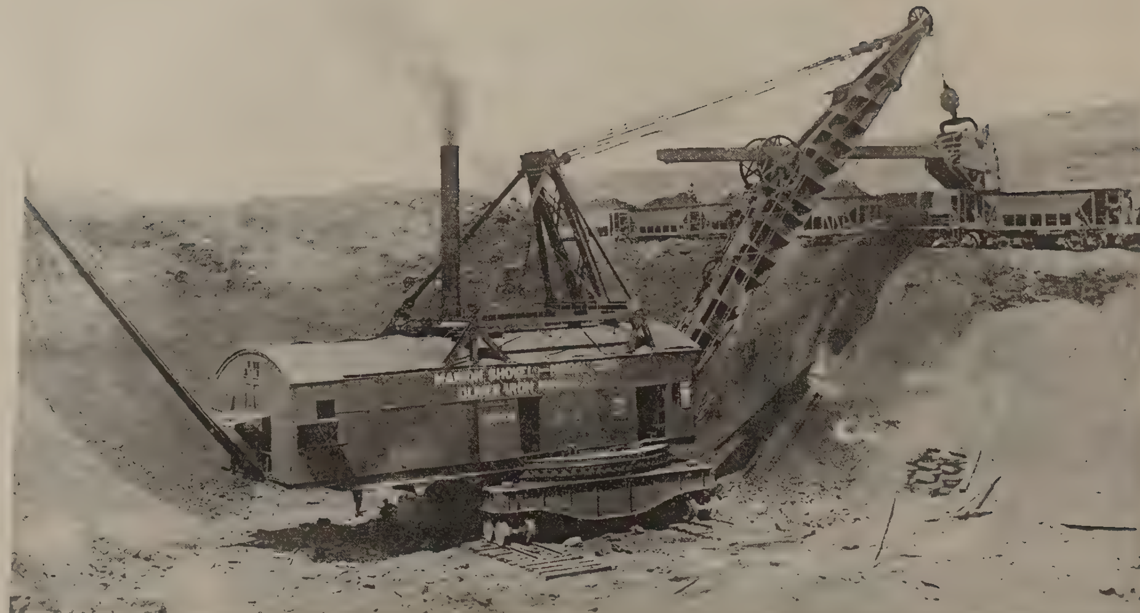
At the beginning of the nineties we find that another marked change has taken place. Air drills were improved, shops were erected and mine equipment was manufactured on the property. The ore skips gave way to the car cage with its landing gates and, at that time, wonderful safety dogs. The car cage was made necessary because the first ore crushers (of the jaw type) had been installed and the car that was loaded with ore from the underground chutes was trammed to the shaft, run into the cage, hoisted to the surface, then run off and it finally dumped its load into the crushers, where the chunks were reduced to the proper size and the ore then run out onto the stockpile.

At this stage we see the use of stockpile trestles that had considerable grade from the crushers to the pile. The car was first attached to one end of the cable with a counter-weight running on a very steep incline attached to the other end of the cable. The idea was that the loaded car would pull the counter-weight to the top of the incline and when the car was dumped the counter-weight would pull it back. This was improved upon by later double tracking the trestle and two cars were fastened, one to each end of the cable, and in this way the loaded car running out always pulled the empty car back to the crusher.

The next step was the introduction of the first crude electric arc lighting system installed at the Soudan mines, the installation of large hoisting engines, of the Corliss or drum type, and large air compressors. About this time the railroads brought out their 25 tons capacity ore cars.

At this time, in the early nineties, mining in a small way was started on the Mesabi Range. Shafts were sunk and underground method adopted, but as ore bodies were discovered having a very shallow overburden, it was soon decided to strip this overburden. This was started by using teams, scrapers and wagons, then teams and 1-ton side dump cars. But hand stripping was too slow and the next move was the introduction of the first steam shovel.

It is interesting to note that the first shovel used for loading stockpile ore at the Soudan mines was in danger of destruction by the miners, presumably because it displaced scores of men who made a practice of loading stockpile ore by hand and who thought they were being deprived of a livelihood.



300-ton Marion Shovel loading ore at Hull-Rust Open Pit, Hibbing. Shovel has 80-foot boom, makes cut 120 feet wide at depth of 40 feet between loading track. Weight of boom 48 tons. Weight of dipper stick 18 tons.

The early types of steam shovels were far different from the machines in use today. The dipper was thrust out by a steam piston with the cylinder fastened about the middle of the underside of the boom. The swinging was done by two steam cylinders, one on each side of the shovel and the piston of each was fastened to one end of a rope that was wrapped around the circle. When one piston was forced out the other piston was forced into its cylinder and the boom was swung in one direction; reversed operations of the pistons swung the boom in the other direction. These first shovels were all friction driven from one main engine and at first were fitted with upright boilers.

With the advent of steam shovels in stripping work came the introduction of small steam locomotives known locally as "dinkies" and weighing from 6 to 12 tons. The track consisted of 20 to 30-lb. rails, 24 to 36-in. gauge of track and the trains consisted of 1-yd. to 4 cu. yd. side dump cars.

With the introduction of the open pit method of mining there seemed to be no reason why the railroad cars could not be taken down into the pit and loaded. This method was adopted and has continued to date. The only change has been in the use of larger cars.

After the open pit mines were decided to be most advantageous in the point of economy on the Mesabi Range, the operators began improving their equipment by increasing its size and capacity. The 35-ton pioneer shovel was developed until it weighs 300 tons and is operated by either steam or electricity today. Its dipper has a capacity of 16 times that of the original; its capacity both in reach and loading is many times that of the shovels of the early days. The little 1 cu. yd. dump cars of wood construction have grown to a capacity of 30 cu. yds. The latest cars are constructed entirely of steel and are automatically operated by compressed air. The small 6-ton "dinky" steam locomotive has given way to a standard locomotive weighing 60 to 100 tons on the drivers, equipped with the latest air brake apparatus, using superheated steam and is electric lighted.

The small steam hoist, air compressors and pumps gave way to larger and more improved types and finally steam equipment is being replaced by electrically driven machines. The first ore may have been hoisted in a bucket by a horse winch, but today the ore is loaded from self-measuring pockets into self-dumping skips, and hoisted by high speed electric hoists with such safety appliances that an overwind is practically impossible.

Type of steam shovel used on the Mesabi Range, with safety appliances.

The original hand tramming, underground, has given way to the mule, and the mule to the electric and gasoline locomotives. The air rock drills of the old Rand type have been replaced by the more efficient water piston type, and the end dumping main level car is no more, but in its place is found either the gable bottom or the more speedy rotary dump, in which a whole train can be dumped at once.

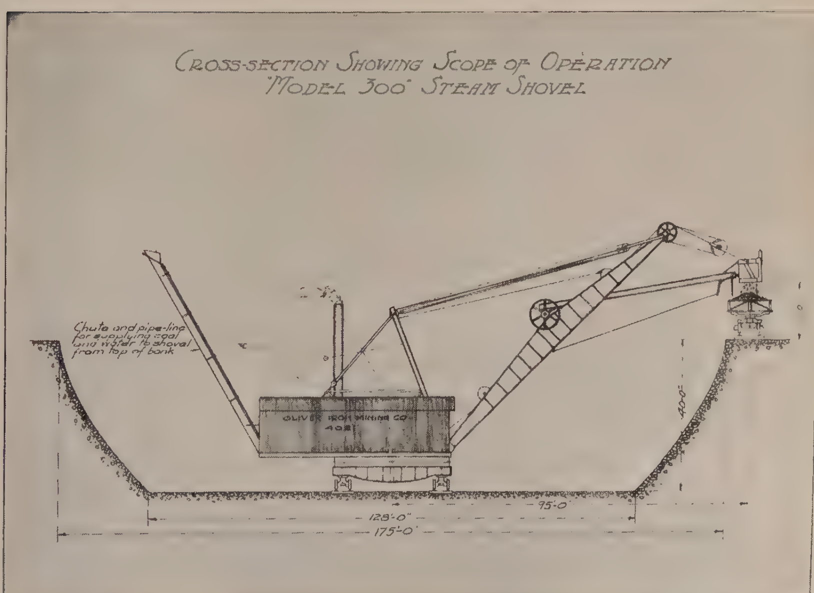
Of late years the operators have been confronted by a very serious problem: namely, the growing scarcity of labor. The scarcity of labor is responsible for such devices as track shifters and tie tampers in the open pits, doing better and more efficient work with fewer men, and which are valuable additions to the Range machinery family. To increase the efficiency of labor we ascribe the introduction of such devices as air augers and underground loading machines. Every effort, and much money, is being spent in an endeavor to find some sort of mechanical device that will speed up the mining in shaft mines, but recently nothing has been invented that really marks a definite step forward for greatly increased production, as did some of the early inventions.

Not only has machinery been invented to make mining easier and more profitable, but lately we have seen the erection of Ore Washing Plants for mechanical treatment of siliceous ores, and drying plants for driving off excess moisture. In the early days certain ores that were mixed with rock and considered poor, were seldom shipped; today we find such ores screened mechanically, sending the rock to the waste pile and the ore into railroad cars.

All through history of iron mining in Minnesota one great fact seems to stand out above everything else, and that is the wonderful progressiveness of the industry, the constant striving for better and more profitable methods and equipment. One needs but to think of the horse-winch and bucket laboriously hoisting one ton of ore several times per hour in the wilderness forty years ago, and then look at the 300 ton shovels scooping up 16 tons of ore per lift almost every minute; at the throbbing locomotives, power plants, and the many busy and prosperous communities, and then realize that this wonderful progress was made possible mainly because the men engaged in the mining industry from the pioneers to the men of today have been vigilant and ever on the lookout for better and more rapid means of doing this work.

Ore train leaving Hull-Rust Pit, Hibbing, Minn.

A "Model 300" Steam Shovel in Ore.



Cross section showing scope of operation of a "Model 300" steam shovel.

BENEFICIATION OF LOW GRADE IRON ORES

During the last ten years great strides have been made, on the Mesabi range, in the practice of beneficiating low grade iron ore material. By beneficiation is meant all methods of removing impurities, and raising the iron content to a point where it can be sold in open market, the principal impurities being silica and moisture. The general processes to which low grade iron ores are amenable are as follows:

1. **Thermal**

   (a) Drying; removes hydroscopic or atmospheric moisture.

   (b) Calcining; removes carbon dioxide from iron carbonate, molecular water from hydrated hematites, and atmospheric moisture.

   (c) Roasting; removes sulphur, carbon dioxide, molecular water and atmospheric moisture.

   (d) Agglomeration; primarily for the purpose of preparing finely divided material for blast furnace; briquetting and sintering.

2. **Mechanical**

   (a) Screen sizing; removes rock and sand.

   (b) Classification; removes sand by means of currents of water of varying velocities.

   (c) Log washing; removes fine sand.

   (d) Jigging; removes larger particles of impurities than is possible by log washing. Certain types of jigs remove fine sand.

   (e) Reciprocating tables; recover fine iron particles from sand discarded by above processes.

   (f) Magnetic separation; applicable to the commercial separation of the magnetic oxide of iron from gangue material. From a scientific standpoint it is possible to separate certain hematites and limonites from their gangue.

   (g) Miscellaneous processes; comprise dry concentration, electro-static separation and other processes.

The economic features that bear upon the commercial success of any process of beneficiation are:

1. Character and size of ore body, and the proportion of merchantable or direct shipping ore to ore that can be treated.

2. Results of treatment tests, recovery, etc.
3. Cost of mining.
4. Royalty.
5. Cost of beneficiation.
6. Cost of marketing.
7. Grade and market value of product.

The profit per ton that can be made by beneficiation will be small, and it is only by handling large tonnages that the proposition becomes financially attractive.

Various estimates of the exhaustion period for Lake Superior merchantable ores run from thirty to fifty years, but there is an almost inexhaustible supply of low grade ores awaiting development.

At this time four of the above methods of beneficiation, i. e., Drying, Screening, Log Washing, and Table Concentration are in use, and a plant for a fifth process, magnetic concentration, is now under construction.

Drying plants may be seen at the Brunt mine, at Mountain Iron, and at the Whiteside mine, at Buhl, the latter being inactive at this time.

Crushing and screening plants are to be found at the Leonidas mine, Eveleth; Morris, Albany, the Buffalo-Susquehanna, the Warren and Webb mines at Hibbing.

The washing plants are located at the Leonidas mine, Eveleth; Webb mine, Hibbing; Hawkins, La Rue, Quinn-Harrison,

The Brunt Ore Drying Plant.

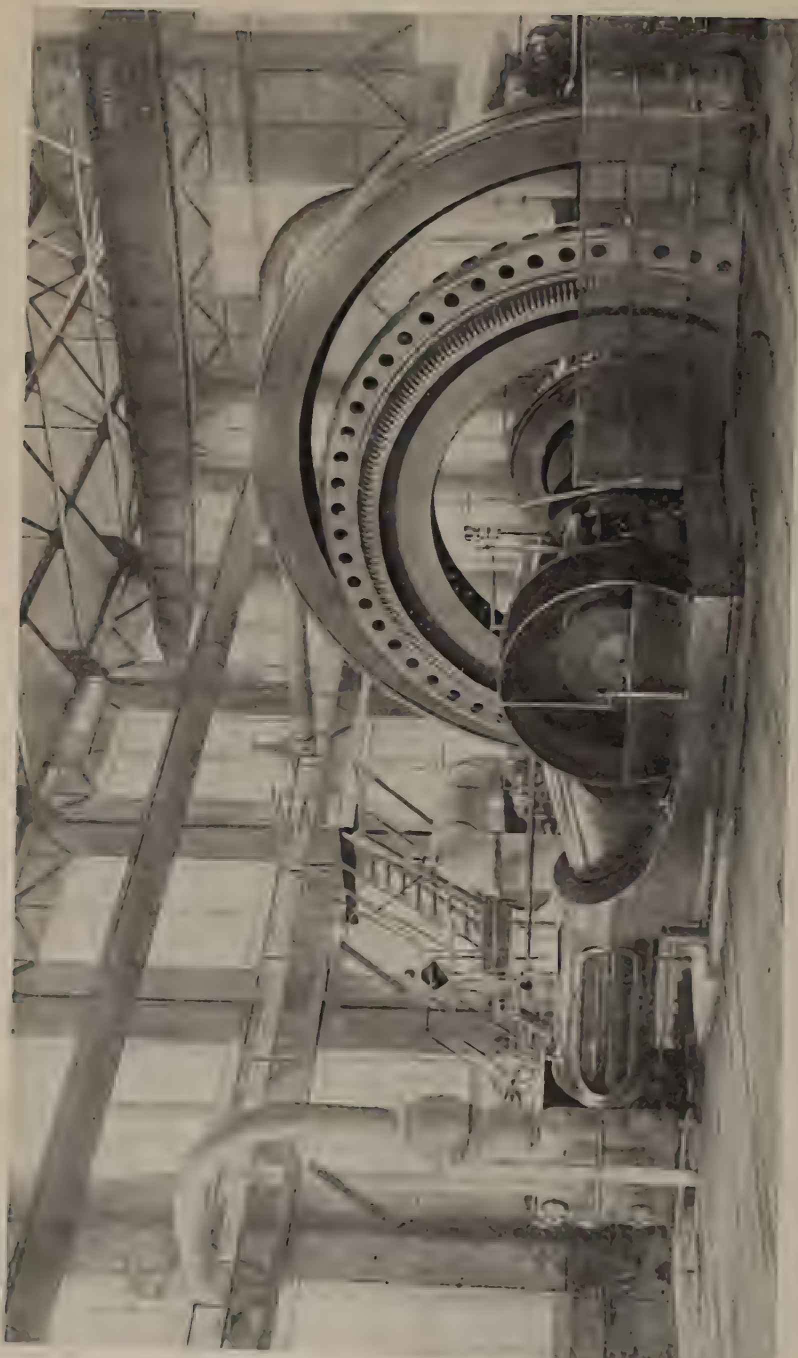
Crosby, Shada and York at Nashwauk; the Draper, Majorca; Hill Annex at Calumet, Patrick at Pengilly, Danube at Bovey, and the Trout Lake concentrator at Coleraine.

The Brunt Ore Drying Plant. In 1910, M. A. Hanna & Co. built an experimental drying plant at the Hollister mine, Crystal Falls, Mich. This was the first plant of this nature built in the iron districts of Lake Superior. The ore to be dried was of very painty nature, being high in alumina, and the moisture content was in the neighborhood of 18 to 20 per cent. The capacity of this plant was approximately twenty tons per hour. The type of dryer used was what is known as the Cummers Patent Dryer. Considerable tonnage was handled through this plant with satisfactory results. By eliminating a part of the moisture the percentages of the other ingredients of the ore are raised in proportion to the amount of moisture abstracted. It was found by drying the iron ore that such grades as were a few points below the required iron content could be raised to grades that would be accepted as merchantable ore—in other words, taken out of the lean ore class. Many difficulties were encountered at the Hollister plant in the mechanical handling of the materials. As iron ore is of an extremely abrasive nature, the wear and tear on conveyors, elevators, chutes and any other apparatus with which it came in contact was very excessive. This plant was finally dismantled, but not until the ore at the property had been shipped.

In 1911, the above company began building a dryer of much larger proportions at the Brunt mine, Mountain Iron, Minn. The capacity of this plant was to be 120 tons per hour. The first year of its operation only two units were installed, each having a capacity of forty tons per hour. These also were the Cummers Dryers, and were designed especially for iron ore. A great many mechanical difficulties were enconutered in this installation, due to the stickiness and the high moisture content of the ore to be handled. After the first year's operation it was found necessary to practically tear down the whole plant and rebuild it along different lines, as the experience gained in the first year's operation proved that the equipment was entirely inadequate to cope with the situation. The wet ore bins were changed; the feeders required an entirely different arrangement. To take the place of conveyor belt, a bucket conveyor was installed, and the whole plant was changed over from steam

driven equipment to individual electric motor drives. This same year two more dryer units were installed. These were of the Ruggles-Cole type. Each of these machines had a capacity of twenty tons per hour. Again an endless number of mechanical troubles were encountered with this equipment, the gear drives, etc., being entirely too light for the work imposed upon them. These were enlarged and rebuilt. The wear and tear on this equipment was very severe, and these dryers were practically rebuilt throughout with the exception of the outside shells. At this time large dust collectors were installed for collecting the dust which was carried over by the fans from the dryers. The theory was that the ore should be dried down to a moisture content of 4 or 5 per cent. The first cargoes shipped to the lower lake ports gave a great deal of trouble due to the dust which was given off during the handling, and finally the moisture content of dried ore was increased to between 8 and 11 per cent. When the ore was dried to this moisture content very little dust was given off from the dryers; consequently the use of dust collectors was discontinued, the fans discharging directly to the atmosphere through short stacks. The continuous bucket conveyor was finally discarded on account of the high cost of upkeep and delays caused by breakage and repairs. This was taken out and replaced by continuous bucket elevators which are giving very satisfactory results to date.

The ore that is being dried at the Brunt mine contains from 16 to 22 per cent moisture and is reduced to about 9 or 10 per cent moisture content. The furnace men are very well pleased with the structure of the ore after it has been dried, as in drying it nodulizes or rolls into small pellets, which makes a very satisfactory furnace ore. At the same time that the dryer was being built at the Brunt mine, the Shenango Furnace Company installed a large plant at the Whiteside mine, at Buhl. This plant consisted of four large Ruggles Cole type dryers, each having a capacity of thirty tons per hour. The location for the Whiteside dryers was ideal as the ore was transferred through the plant entirely by gravity, no conveyors, elevators or other ore handling equipment being necessary outside of bins and feeders. The Whiteside plant experienced considerable difficulty similar to the Ruggles-Cole units at the Brunt, the gear drives, etc., being too light in design to stand up under the severe work. A new driving mechanism was finally installed at this



Power House at Trout Lake, Coleraine, Minn.

plant and some very satisfactory results were obtained. At the present time this plant is not in operation.

In iron ores which have a natural iron content of 45 to 48 per cent, and a moisture content of 14 to 20 per cent, an abstraction of 2 per cent moisture will increase the iron content approximately 1 per cent. Thus, if from an iron ore containing 48 per cent iron, as mined, 6 per cent moisture be abstracted, it yields a product of approximately 51 per cent iron. Considerable money has been spent in developing the drying of iron ore, and the results have been very satisfactory.

Butler Brothers, contractors, have a drying plant under construction at the present time at the Lamberton mine, at Hibbing.

Trout Lake Concentrator. The first attempt to wash Mesabi ores was made in 1901-2, when a carload of ore was sent from the Arcturus property to Cedartown, Ga. The results justified further investigation, and in 1903-4 a small experimental plant was built at the Holman mine. In 1905, the Oliver Iron Mining Company became interested, and after exhaustive investigations conducted during the following four years erected the present Trout Lake concentrator. The work was commenced in April, 1909, and the plant was ready for use in 1910. It is located on the east side of Trout Lake, readily accessible from all directions. The mill building is of heavy steel construction throughout, 255 feet long, 162 feet wide, and 124 feet high, enclosed with corrugated iron. The approach to the mill is an earth fill, some 4,000 feet long, containing several million cubic yards of stripping from the Canisteo and Walker pits. It has a maximum height of 125 feet and was planned to accommodate four tracks. A steel trestle, 650 feet long, connects it with the mill. At the opposite end of the mill, 300 feet of additional steel work is in place and is now being used for tail track; it can be utilized for an addition to the mill if need arises.

The power and water for the mill are supplied from a power and pumping plant 7,000 feet distant on the shore of Trout Lake. The pump has a capacity of 500,000 gallons per hour. The water

Concentrator, Coleraine.

is pumped direct to a 100,000-gallon supply tank at the mill. All the machinery in the mill is electrically driven. A 1,250 k.v.a. direct-connected generator transmits electric power at 6,600 volts to the mill, where it is stepped down to 440 volts.

The total amount of steel in the mill building, approach, tail-track and power plant structures is approximately 7,000 tons. The total cost of mill and equipment, according to the published report of the United States Steel Corporation, approximates $1,500,000.

The concentrating machinery is arranged in five units, each complete and capable of independent operation. This was done in order to keep the machines within reasonable size, to be able to handle separately the ores from different properties at the same time, and to increase the capacity. The tail-track already mentioned is long enough for seven additional units. The crude ore from the different mines is hauled to the mill over the big fill approach and trestle and dumped into the bins at the top of the mill. Each unit has a separate bin of 450 to 500 tons capacity. The ore is sluiced out from the bottoms of the bins by a hydraulic jet, and descends by gravity through the different machines. The crude ore tracks are 90 feet above the concentrate tracks. The ore is handled entirely by gravity; there is no elevating machinery to get out of order, other than the sand pumps necessary to lift the table concentrates to dewatering tanks over the concentrate bins.

Each unit consists of the following equipment, listed in the order in which the crude ore passes through it. Reference to the unit flow-sheet (Fig. 100) will help to an understanding of the process.

FLOW SHEET OF TROUT LAKE CONCENTRATOR.

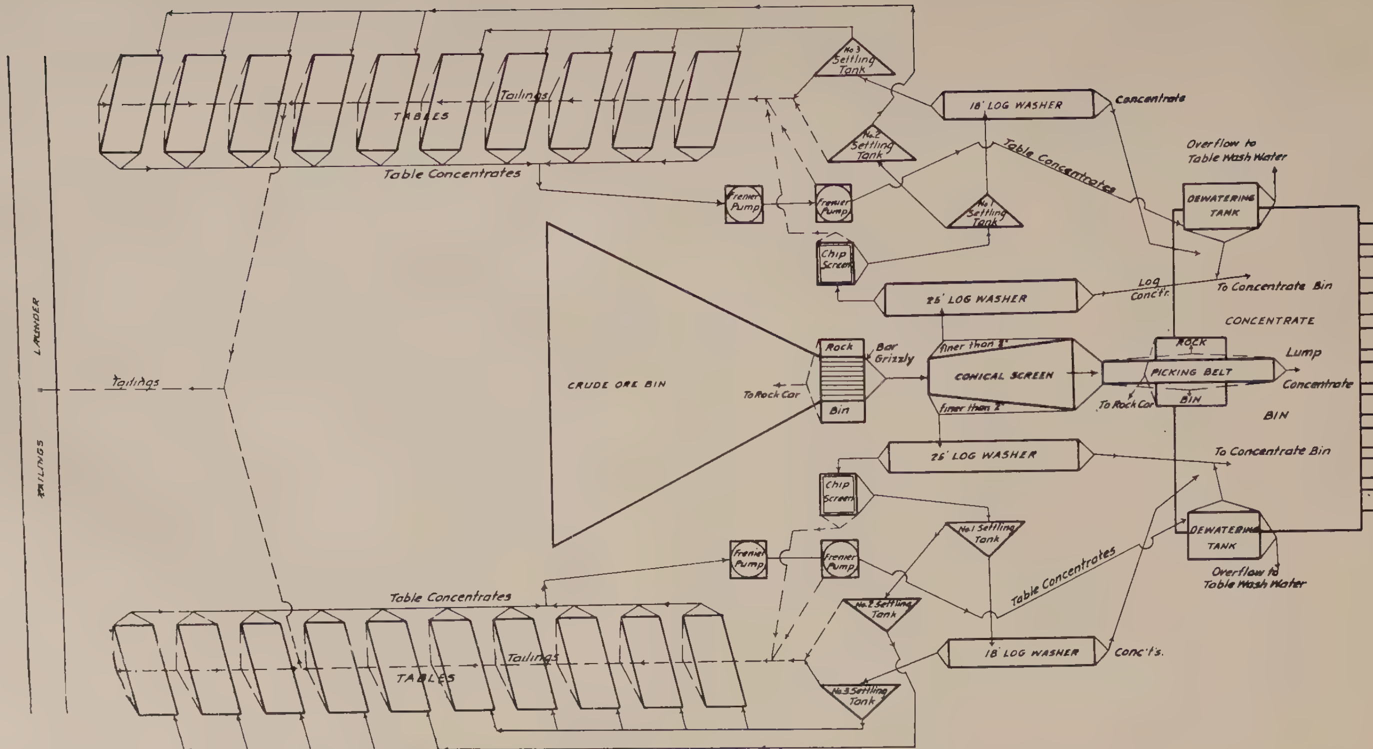
One crude ore bin and one bar-grizzly.

One 20-foot conical revolving trommel with 2-inch openings.

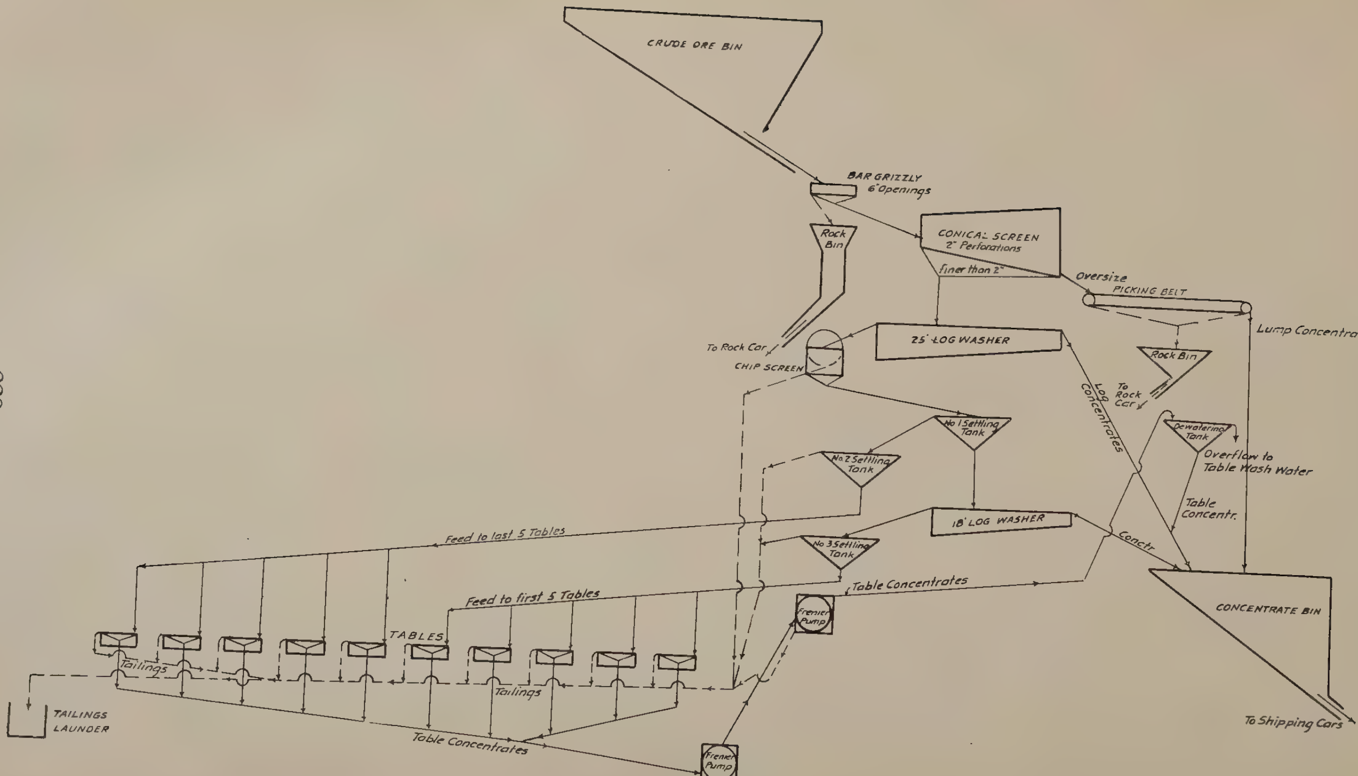
One picking-belt, to receive and convey the trommel oversize to the concentrate bin. (The taconite chunks are picked off the belt by hand and dropped into a rock bin.)

Two 25-foot log washers, one on either side of the trommel to treat the trommel "throughs," discharging a product into the concentrate bin.

Two chip-screens, one for either "log," receiving "log" overflow.



Oliver Iron Mining Company—Flow Sheet—Trout Lake Concentrating Plant—Plan.



Oliver Iron Mining Company—Flow Sheet—Trout Lake Concentrating Plant—Elevation.

Two settling tanks, receiving chip-screen "throughs."

Two 18-foot "turbos" (small log washers to treat fines), receiving the tank settlings, discharging a concentrate directly into the concentrate bin.

Four settling tanks receiving the overflow from turbo and first settling tanks.

Twenty Overstrom tables, arranged in two rows of ten each, to treat the settlings from the four settling tanks just mentioned.

Eight Frenier spiral sand pumps (four primary and four relay), to pump the table concentrates to dewatering tanks from which they discharge directly into the concentrate bin.

The mill product thus consists of belt product, log-, turbo-, and table-concentrates. Each unit has its own concentrate bin of ninety tons capacity. Tracks for ore cars run directly under the bins, a separate track serving each bin. The cars are stored in a yard south of the mill, from which they can be spotted under the bins by releasing the brakes, as the grade from the yard is down towards the mill. The tailings consist of chip-screen discharge, No. 2 and No. 3 settling-tank overflow and table tailings. They are collected by launders in the mill basement and discharged into a concrete launder outside the table addition to mill. This launder discharges into Trout Lake, some 2,000 feet distant. The amount of water used per unit is about 1,500 gallons per minute, or 90,000 gallons per hour, approximately 360 gallons per ton of concentrates.

The rock picked off the belt and bar-grizzly is drawn from the rock pockets or bins into a rock car and hauled by an electric motor to a stockpile east of the mill. One motor and car serves all five units. One 100-h.p. electric motor drives the trommel, picking belt, logs and turbos; one 15-h.p. motor drives the tables and chip-screens; one 20 h.p. motor runs the sand pumps in the basement of the mill.

The mill building is commodious and the machinery is conveniently arranged. Safety devices, machine guards, and protecting railings are installed throughout for the safety of employees.

In 1910, the mill was operated on two eleven-hour shifts. In 1911, this was cut down to two ten-hour shifts. The average capacity is nearly 400 tons of crude ore per hour per unit, the maximum being 900 tons. The largest tonnage washed in one season of six months was over 4,000,000 tons of crude ore. The mill can not be operated in freezing weather, and its operating

season coincides with the ore-shipping season. Nearly 100 men are employed on the day shift, and 75 to 80 on the night shift.

The average grade of crude ore varies greatly, depending on the character of material being treated and the local conditions at the time of mining. The concentrate product varies within wide limits, depending upon the character and class of ore, just as the grade of "direct-shipping" ores varies greatly. This is not a matter of degree of concentration produced by the mill, but rather the amount of concentration and enrichment produced by nature.

The results obtained vary widely for different ore bodies and even for different layers in the same ore body. The quantity of rock sorted out in the pit is so variable that the mere statement of mill recovery might give a very misleading idea of the total percentage of recovery from these low grade ore bodies. It may be authoritatively said that the mill has satisfactorily solved the problem of economical handling of western Mesabi ore bodies, a most important achievement in the line of conservation of our national resources.

The several smaller washing plants listed above consist of two, one, or one-half unit installations similar to that of the Trout Lake plant.

The Concentration of the East Mesabi Magnetites. The last method of treatment to be considered, and the last to make its appearance in the Lake Superior district, is magnetic concentration. This method of beneficiating iron ores has been in use for many years in New York State and Canada, and some foreign countries, but, until recently, it has not been used in this district.

The whole process of magnetic concentration as applied to the eastern Mesabi magnetites is a good illustration of the manner in which the various types of machines can be made to work together so as to produce a high-grade furnace product from an ore material containing only 25 per cent of iron in the form of magnetite. The hard rock is first crushed to about three-inch size and is then passed over a magnetic cobber. The field strength of this cobber is so adjusted that all of the coarse material containing no magnetic iron is discarded as tailing. The concentrate from this cobber is still too low grade to be useful, and is, therefore, crushed again to two-inch size. This material is passed over a second cobber and the worthless gangue again discarded. This process of crushing, cobbing and discarding worthless material continues until the product has been reduced

to about ¼-inch size. When this stage has been reached, approximately one-half the ore has been discarded as tailing and the other half contains practically all of the magnetic oxide that was originally present in the rock. This ¼-inch material, however, still contains too much gangue to be considered a desirable furnace product. It is, therefore, ground wet in ball mills until it will all pass a 100-mesh screen. This fine material is concentrated by magnetic log-washers in which the final separation is made. The concentrate produced by these machines is then dewatered by the use of continuous filters in the tank of which the fuel for sintering is mixed. The filter cake is conveyed directly to the sintering plant, where the ore is agglomerated. After being sintered the ore is screened in order to remove any fine material, and only the clean coarse sinter is shipped to the furnaces.

TRANSPORTATION.

Duluth & Iron Range Railroad. The Duluth & Iron Range Railroad was built from Two Harbors to the Vermilion range at Tower, a distance of 67.6 miles, in 1884, and extended to Ely, twenty-one miles east of Tower, in 1888. It was built into Duluth in 1886, and branches were extended from its main line to the Mesabi mines in 1892 and 1893. The original grades on this road are very steep, going north, and in the thirteen miles from Two Harbors to Highland there is a rise of 1,150 feet. A new line between these points has been built with an increase of three miles in distance and with maximum grades of 1 per cent.

Duluth, Missabe & Northern Railway. The Duluth, Missabe & Northern Railway was constructed from Stony Brook to Mountain Iron, a distance of 48.62 miles, in 1892. The Biwabik branch from Iron Junction to Biwabik, a distance of 15.54 miles, was constructed in 1892. The Superior branch from Wolf to

Type of locomotive used by D. M. & N. Ry. on hill from docks to Proctor yards.

Section of D. M. & N. Ry. main line showing double track, 100 lbs. to the yard rail, steel ties and rock ballast.

Locomotive. Type used on the Mesabi Range. Note guard rails for protection of men.

Right-of-way on the Duluth & Iron Range Railroad.
This right-of-way is conceded by the State Foresters to be in ideal condition.

Hibbing, a distance of 16.06 miles, was constructed in 1893. The Alborn branch from Coleraine Junction to Coleraine, a distance of 53 miles, was constructed in 1906. The total main line mileage is 242 miles, of which 82 miles from Duluth to Hibbing is double tracked.

The maximum south bound grade against the loads is 0.3 per cent. The maximum north bound grade against the empties is 2.0 per cent, this extending only six miles from the ore docks to the south end of the yard at Proctor. The entire main line, with the exception of a small part of the Biwabik branch, is laid with 100-pound steel rails. The balance of the tracks are laid with 80-pound.

Seven miles of the double track between the ore docks and Proctor is rock ballasted; the balance of the road is ballasted with gravel.

The shops and classification yards are at Proctor. The ore docks, the largest in the world, are at Duluth.

Great Northern Railway Line, Mesabi Division. The Great Northern Railway line acquired what is now its Mesabi Division, over which line ore is transported from Mesabi range mines to docks at Allouez, Wisconsin, by purchase of the Duluth, Superior and Western Railway (Duluth and Winnipeg) in 1898. At time of purchase this line extended from Duluth to Deer River, connecting with the Duluth, Mississippi River and Northern Railway at Swan River, this latter extending to the mines. In 1898 the purchase of the Duluth, Mississippi River and Northern Road was effected, which gave the Great Northern a line through to Barclay Junction (now Chisholm), Minnesota. In 1900 and 1901, extension was built from Barclay Junction to Virginia, and in 1901 and 1902, line was built from Ellis (near Virginia) to a point on the old D. S. & W., known as Brookston now, then Stony Brook. In 1902 and 1903, what is now designated as the "South Range Line," was constructed from point near Hibbing (Kelly Lake) to connect with main line a few miles out of Virginia (Flanders).

A cut-off has been built also, known as the Kelly Lake-Fermoy Line, running from point immediately south or east of Kelly Lake to west end of Fermoy, passing track on the Brookston line; length, 23.4 miles; ruling grade, east bound 0.1, west bound 0.6. The actual distance from Kelly Lake to Fermoy is 24.074 miles. The object of this "cut-off" is to make a shorter haul between the mines and Allouez ore docks.

Allouez to Swan River, 87 miles; Swan River to Chisholm, 33 miles; Chisholm to Virginia, 18 miles; Ellis to Brookston, 46 miles; South Range Line, 11 miles. There is a uniform grade of about .04 per cent over entire Mesabi Division.

Shops at Superior, Wisconsin. Ore docks and yards at Allouez, Wisconsin, for receiving ore lake end. Large assembling yard at Kelly Lake, for mine end.

Operation. All of these roads transport ore from the Mesabi range. The Duluth & Iron Range handles the ore from the Vermilion district. The Cuyuna range is tapped by the Northern Pacific and "Soo" lines.

In addition to the large tonnages that must be handled with dispatch there is a necessity for making and maintaining certain ore grades and loading them into the holds of steamships carrying from 5,000 to 14,000 tons. Each boat must be loaded promptly with a fixed tonnage for a certain draught; and each cargo must analyze within a fraction of a certain guaranteed grade.

At the mines the loaded railroad cars are collected in yards where the trains are made up. These cars are sampled in lots of

Loading logs on cars for shipment to the mines.

five or ten, and while the train is on the way to its destination the samples taken are rushed through a laboratory and the results made known to a chief grader.

The grading office is advised of the arrival of a boat due about twenty-four hours in advance, also the amount and grade of ore that it will carry, and with the analysis of the trainload at hand, the dock is laid out in what is locally termed "ore blocks." The chief grader disposes of the ore as will best suit his purpose and wires disposition to the docks.

When the vessel arrives it takes its load from the blocks prepared for it. Often the "blocks" run "off grade" taking care of the ore as it comes, and when this occurs the cargos are neutralized by drawing from special "blocks" that analyze "on grade" and are held in reserve for this purpose. These mixtures are mathematical rather than physical, but through handling become homogeneous when they finally arrive at the furnaces. In spite of the fact that there are numerous opportunities for errors and delay, the system works with precision.

Rail Transportation Data

	D. & I. R.	D. M. & N.	G. N.
Size of trains of ore: No. of 50-ton steel cars loaded.......	50	90	120
Size of locomotives..	D. & I. R.	D. M. & N.	Mallet
Type of locomotives	Mikado	Santa Fe	Mallet
Class of locomotives	2-8-2	2-10-2	2 8 8-2
Cylinders	27″x30″	27″x32″	26″x40″x32″
Drivers, diam.......	58″	60″	57″
Wt. of engine, lbs...	294,000	352,000	436,000
Tractive power, lbs..	59,250	69,400	95,513

Equipment Data

	D. & I. R.	D. M. & N.	G. N.
No. of locomotives..	110	131	46
No. of steel ore cars (50-ton)	5,718	8,168	4,300
No. of other freight cars	1,301	1,094	
No. of passenger, express and baggage	27	39	
Total work equipm't	102	64	
No. of trains per 24 hours	24	30	

LAKE TRANSPORTATION

One of the first ships of commerce to arrive in the harbor of Duluth was the Meteor, in September, 1868. The capacity of this boat was 500 tons.

The first cargo of ore shipped from Minnesota was carried by the Steamer Hecla. The ore was loaded at Two Harbors, at the Duluth and Iron Range dock, on August 19, 1884, and consisted of 1,427 tons.

At the present time about 400 boats are used in the ore carrying trade. The capacity of this fleet is estimated at 55,000,000 tons of ore a season. This is exclusive of the transportation of coal and grain.

The Pittsburgh Steamship Company, a subsidiary of the Steel Corporation, own and operate 106 boats.

The net cost to the shipper of moving a ton of iron ore from the Mesabi range to a lower lake port for season 1920 is $2.163. This is divided into $1.00 rail haul to Duluth, with 3 per cent war tax; $1.00 lake haul, with 3 per cent war tax; and a $0.10 unloading charge, with 3 per cent war tax. By unloading charge is meant the cost of hoisting the ore from the hold to the rail of the vessel. The buyer pays $0.06 from rail of vessel to car on all ore for direct shipment. During 1912, ore was carried on the Great Lakes over an average distance of 1,000 miles for as low as 50 cents per ton, the boat owners paying the unloading charge of 10 cents a ton.

An idea of the size of the more recent boats constituting the ore carrying fleet is given by the following figures:

Steamer—	Length	Width	Tonnage Gross Tons
W. P. Snyder, Jr.	617	64	14,000
L. S. De Graff	605	60	12,900
W. B. Kerr	605	60	12,300
Thomas F. Cole	605	58	12,000

The usual time of loading an ordinary boat of about 10,000 tons capacity is six hours. On July 6, 1919, the steamer D. M. Clemson departed with 15,355 short tons of iron ore, the record load. She came into Duluth entry at 6:15 P. M. on the 5th and left at 12:35 A. M. on the 6th, being in port six hours and twenty minutes.

The record actual loading time was made July 17, 1919, when the steamer D. G. Kerr took a load of 12,817 gross tons of

-Type of ore carrier on great lakes.

ore, at the D., M. & N. docks. The actual loading time was thirty-five minutes, the total time at the dock was eighty minutes, and total time in port three hours and five minutes.

On June 23, 1920, the Homer D. Williams entered the Duluth ship canal light at 5:00 A. M. and passed out at 8:50 A. M., or within three hours and fifty minutes, with 13,000 gross tons of ore. To appreciate this performance, one must bear in mind that the ship had to traverse five miles of river channel, pass through two draw bridges, shift at the docks and retrace the journey to the ship canal, outward bound.

The average haul to lower lake ports from the head of the lakes is 850 miles. The time of a round trip is about ten days.

In 1919, the navigation season for inter-lake traffic covered a period of 240 days. This is reckoned from the first arrival from lower lakes on April 11 to the last departure for lower lakes on December 7. Local navigation was still open at the close of the calendar year.

DOCKS

The ore docks are huge structures, from 1,500 to 2,300 feet long, 50 to 65 feet wide, and 70 to 85 feet high above the water line. The more recent docks are built of concrete and steel. They must be strong enough to stand a traveling train of four to five million pounds, and take up a strain of from two to three million foot-pounds in the longitudinal bracing every time a train is stopped on the dock. The pockets are at twelve-foot centers. The hinges of the chutes through which the ore is discharged from the pockets into the hold of the vessel are approximately forty feet above water level.

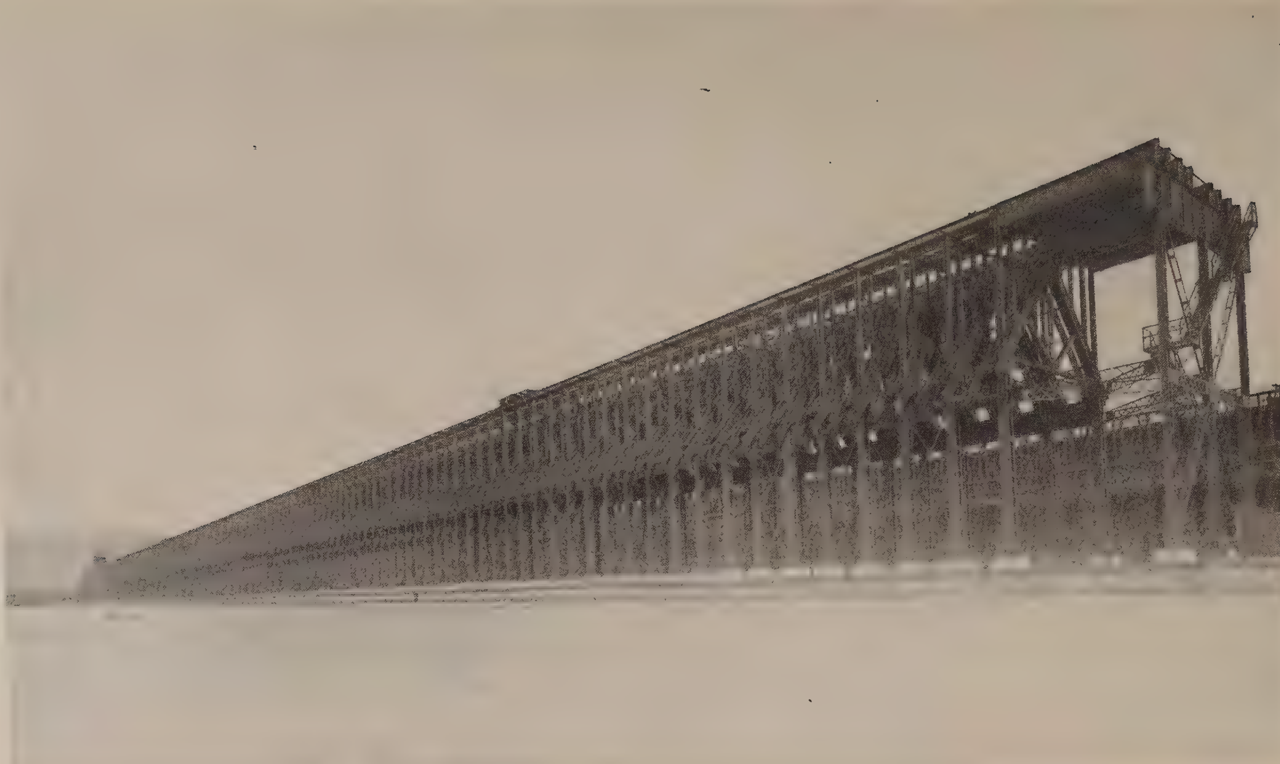
The newer docks represent an investment of $3,500,000, based on pre-war prices of construction and materials.

Following are the main specifications of the docks handling Lake Superior ores:

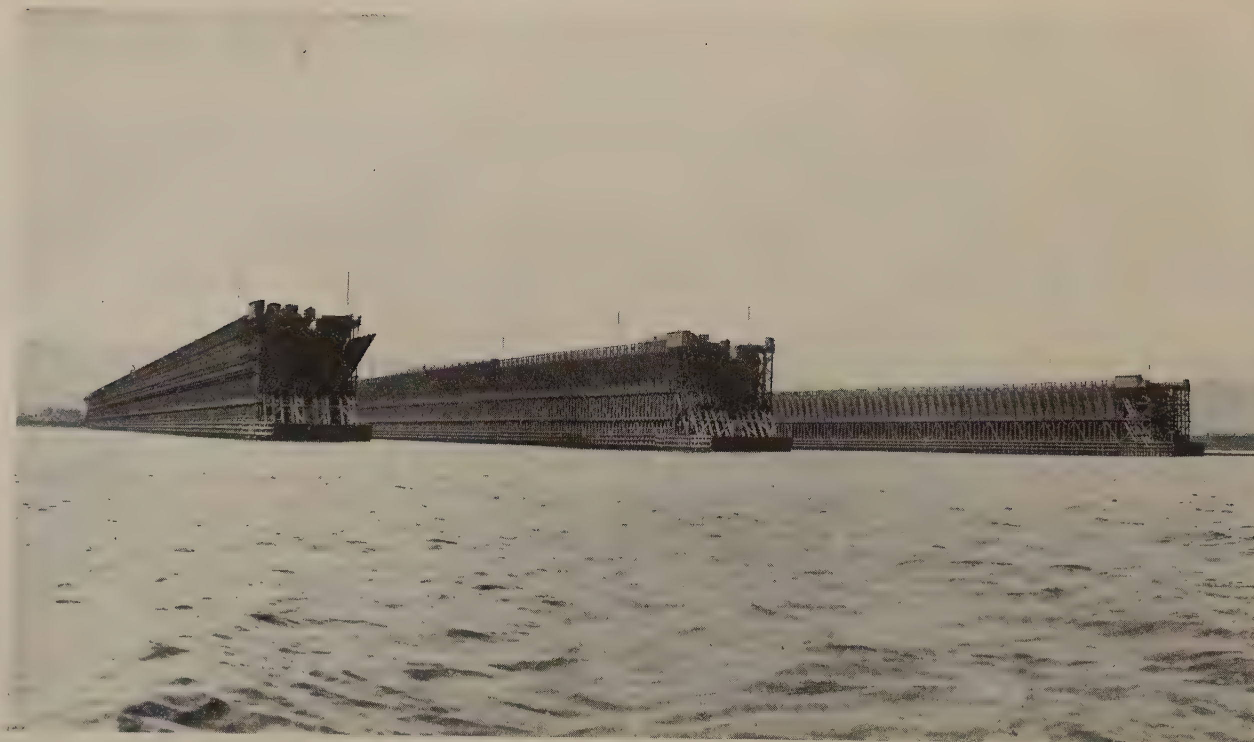
Railway	Location	Dock No.	Number of Pockets	Capacity Per Pocket Cars	Storage Capacity Gross Tons	Height Water to Center Hinge Hole	Height Water to Deck of Dock	Width of Dock Outside to Outside of Part'n Posts	Length of Spouts	Length of Dock	Angle of Pockets	Cubic Feet Per Pocket to Bottom of Stringers	D. & I. Rge. R. R. W. A. CLARK Chief Engineer
C. & N. W. Ry. . . .	Escanaba, Mich. . .	3	226	2 @ 50 tons 1 @ 25 tons	28250	31′ 2″	52′ 8″	37′ 0″	27′ 0″	1356′	45° 0′	1969	
C. & N. W. Ry. . . .	Escanaba, Mich. . .	4	250	2 @ 50 tons 1 @ 25 tons	31250	36′ 6″	59′ 2′	37′ 0″	30′ 0″	1500′	45° 0′	2191	
C. & N. W. Ry. . . .	Escanaba, Mich. . .	5	370	5 @ 50 tons	92500	37′ 9⅝″	70′ 9″	52′ 2″	32′ 1½″	2200′	45° 0′	4142	
C. & N. W. Ry. . . .	Escanaba, Mich. . .	6	320	5 @ 50 tons	80000	40′ 0″	70′ 0″	50′ 2″	30′ 0″	1920′	45° 0′	4114	
C. & N. W. Ry. . . .	Ashland, Wis.	1	290	5 @ 50 tons	72500	39′ 0¼″	72′ 1″	50′ 2″	30′ 0″ 32′ 1½″	1740′	45° 0′	4100	234 spouts 30′ long 56 spouts 32′ 1½″ "
C. & N. W. Ry. . . .	Ashland, Wis.	2	278	4 @ 50 tons	55600	39′ 2½′	70′ 4½″	50′ 2″	30′ 0″ 32′ 1½″	1668′	45° 0′	3550	234 spouts 30′ long 44 spouts 32′ 1½″ "
C. & N. W. Ry. . . .	Ashland, Wis.	3	200	5 @ 50 tons	50000	40′ 4¾″	73′ 5¼″	52′ 2″	35′ 4½″	1200′	45° 0′	4030	
Total		. .	1934	. . . .	410100	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	
D. & I. Rge. R. R. . .	Two Harbors, Minn.	1	224	5 @ 50 tons	56000	39′ 3″	74′ 0″	51′ 8″	34′ 0″	1376′	48° 0′	4075	Steel and concrete
D. & I. Rge. R. R. . .	Two Harbors, Minn.	2	228	6 @ 50 tons	68400	40′ 3⅞″	80′ 0″	56′ 8″	35′ 0″	1400′	48° 0′	5360	Steel and concrete
D. & I. Rge. R. R. . .	Two Harbors, Minn.	5	168	3 @ 50 tons	25200	39′ 0″	66′ 9″	49′ 0″	30′ 0″	1050′	43° 32′	3126	
D. & I. Rge. R. R. . .	Two Harbors, Minn.	6	148	5 @ 50 tons	37000	40′ 0″	73′ 0″	51′ 3¼″	34′ 0″	920′	45° 0′	4220	Steel and concrete
Total		. .	768	. . . .	186600	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	
D. M. & N. Ry. . . .	Duluth, Minn.	3	384	3 @ 50 tons	57600	40′ 7″	67′ 0½″	59′ 0″	27′ 9″	2304′	45° 0′	2782	Not in use
D. M. & N. Ry. . . .	Duluth, Minn.	4	384	4 @ 50 tons	76800	41′ 9½″	72′ 6″	57′ 0″	30′ 1½″	2304′	45° 0′	3867	
D. M. & N. Ry. . . .	Duluth, Minn.	5	384	6 @ 50 tons	115200	40′ 8″	80′ 5″	56′ 0″	36′ 0″	2304′	47° 30′	5313	Steel and concrete
D. M. & N. Ry. . . .	Duluth, Minn.	6	384	8 @ 50 tons	153600	40′ 4⅛″	84′ 5″	60′ 0″	36′ 0″	2304′	47° 30′	6560	Steel and concrete
Total		. .	1536	. . . .	403200	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	
G. N. Ry.	Superior, Wis.	1	374	6 @ 50 tons	112200	40′ 0″	73′ 0″	62′ 8″	32′ 4″	2244′	45° 0′	4972	
G. N. Ry.	Superior, Wis.	2	350	6 @ 50 tons	105000	40′ 0″	73′ 0″	62′ 8″	32′ 4″	2100′	45° 0′	4972	
G. N. Ry.	Superior, Wis.	3	160	6 @ 50 tons	97800	38′ 9″	77′ 0″	59′ 8″	34′ 0″	960′	47° 30′	4972	
G. N. Ry.	Superior, Wis.	3	166	6 @ 50 tons		40′ 0″	73′ 0″	62′ 8″	32′ 4″	996′	45° 0′	4972	
G. N. Ry.	Superior, Wis.	4	302	6 @ 50 tons	90600	40′ 2″	75′ 0″	62′ 6″	34′ 6″	1812′	47° 30′	5347	Steel and concrete
Total		. .	1352	. . . .	405600	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	
N. P. Ry.	Superior, Wis.	1	102	7 @ 50 tons	35700	40′ 6″	80′ 0″	57′ 2″	34′ 0″	684′	47° 30′	5490	Steel and concrete
		*	100	7 @ 50 tons	35000	39′ 9″	80′ 0″	59′ 2″	34′ 0⅛″	600′	47° 30′	5600	Reinforced concrete
Total		. .	202	. . . .	70700	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	
D. S. S. & A. Ry. . .	Marquette, Mich. .	5	200	4 @ 50 tons 1 @ 25 tons	45000	40′ 0″	70′ 10″	51′ 0″	32′ 4″	1236′	45° 0′	3848	
L. S. & I. Ry.	Marquette, Mich. .	2	200	5 @ 50 tons	50000	43′ 0″	75′ 0″	54′ 0″	35′ 0″	1200′	45° 0′	4590	Steel and concrete
M. St. P. & S. S. M. Ry.	Ashland, Wis.	2	150	7 @ 50 tons	52500	42′ 0″	80′ 0″	59′ 0″	34′ 6″	900′	47° 30′	5100	Reinforced concrete
M. St. P. & S. S. M. Ry.	Superior, Wis.	1	402	6 @ 50 tons	120600	42′ 5⅜″	78′ 0″	58′ 0″	32′ 1½″	2412′	47° 0′	4775	
Total		. .	552	. . . .	173100	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	
C. M. & St. P. Ry. .	Escanaba, Mich. . .	1	240	3 @ 50 tons 1 @ 25 tons	42000	40′ 2¾″	66′ 6″	52′ 0″	120 @ 27′ 120 @ 29′	1500′	45° 0′	2900	
C. M. & St. P. Ry. .	Escanaba, Mich. . .	2	240	4 @ 50 tons	48000	40′ 11½″	69′ 2″	54′ 0″	30′ 4½″	1500′	45° 0′	3150	
Total		. .	480	. . . .	90000	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	
A. C. & H. B. Ry. . .	Michipicoten, Ont.	1	12	. . . .	. . . .	34′ 0″	43′ 4″	25′ 0″	22′ 6″	311¾′	44° 0′	. . . .	Storage trestle 20,000 tons capacity
Can. Nat. Rys.	Key Harbor, Ont. .	1	20	2 @ 50 tons	2000	41′ 5″	61′ 9″	28′ 0″	30′ 0″	240′	37° 30′	2315	

*Extension of No. 1.

Iron Ore Dock No. 5, D. M. & N. Railway, Duluth, Minn.
West side, elevation of steel work.



Iron Ore Dock No. 5, D. M. & N. Railway, Duluth, Minn.
West side, steel work.



D. M. & N. Ry. ore docks, Duluth, Minn.

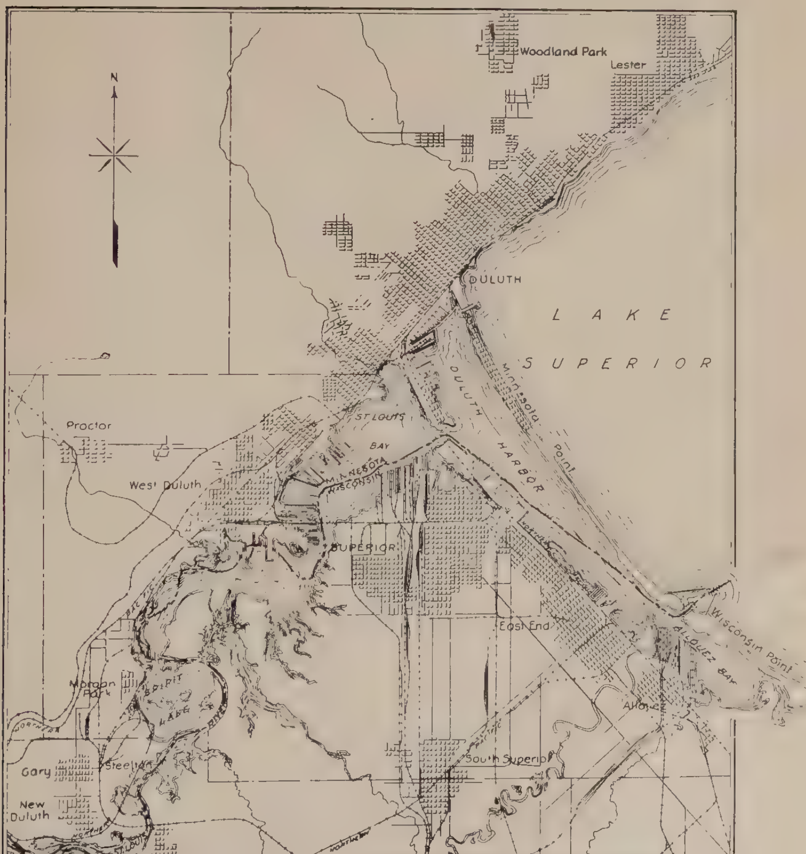
One of the Great Northern ore docks, Superior, Wis.

D. & I. R. Ry. ore docks, Two Harbors, Minn.

DULUTH

The history of Duluth commences with Daniel de Greysolon du Lhut, one of the explorers of the Upper Mississippi who came to the head of the lakes in the summer of 1679. Radisson and Groseillier, and Claude Allouez, a Jesuit priest, are supposed to have visited the head of the lakes, but there is no authentic record previous to that of du Lhut.

In 1792, the fur traders established a fort at Fond du Lac, fifteen miles up the St. Louis River from Lake Superior, but within the limits of the present city of Duluth. In the early 50's, there were a few scattering settlers at Oneota and around the George Stuntz trading post on Minnesota point. In 1855-6, the settlement on Minnesota point was called Duluth, com-



Map of harbor and cities of Duluth, Minnesota, and Superior, Wisconsin.

Duluth, Minn.—1870.

Duluth, Minn.—1920.

memorating the name du Lhut, and organized as a town in 1857. The first board of trustees and town council consisted of William Nettleton, J. B. Culver, Robert E. Jefferson, Grin W. Rice and William Cld. In 1870, the city of Duluth was incorporated, and five years later a portion of the same territory was incorporated as the village of Duluth, and the two municipal corporations were still in existence on March 1, 1887, when the city and the village of Duluth were incorporated as the present city.

The first saw mill in Duluth was erected in 1856-57, on the present site of the ship canal. It cut logs from a virgin forest at the upper end of Minnesota point.

The first railroad was built to the head of the lakes in 1870. The charter for this road had been granted in 1861 to the Lake Superior and Mississippi Railroad Company, afterward called the St. Paul and Duluth, and which is now a part of the Northern Pacific Railroad.

In 1860, the total population of St. Louis County, including Duluth, was 406. Of this number 87 were children of school age. In 1870, the population of Duluth was 1,700; 1880, 3,480; 1890, 33,115; 1900, 52,969; 1910, 78,184; 1920, 99,000.

Duluth now has a well organized Board of Trade, Produce Exchange and Chamber of Commerce. It has fourteen banks with an aggregate capital of $8,632,177, deposits of $50,296,485. The total clearing house business for 1919 was $378,961,698.

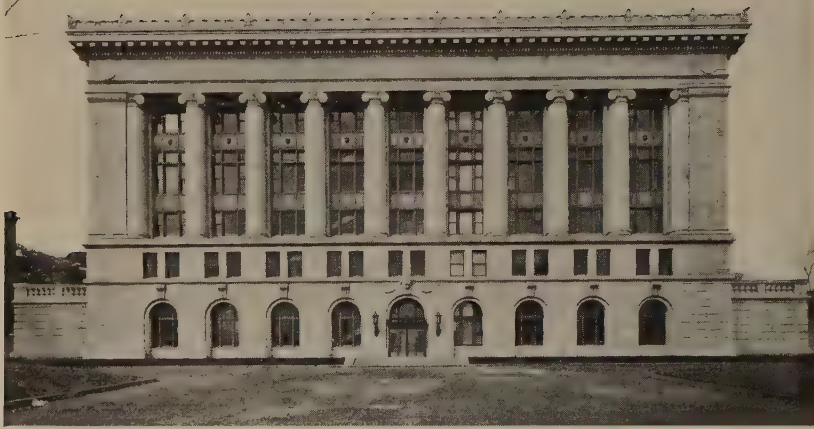
The full taxable value of Duluth property for 1919 was $228,405,183. The total taxes paid for city puposes was $1,184,-140. For taxation purposes, property is valued at 33⅓ per cent of its full value.

The harbor of Duluth and Superior is the finest on the Great Lakes. It is formed by a natural breakwater or sandbar, eight miles in length, extending from the Minnesota to the Wisconsin shore in the west end of Lake Superior. Entrance to it is gained by two canals, known as the Duluth and Superior entries, the Duluth entry being an artificial one. It has forty-nine miles of harbor frontage and seventeen miles of dredged channels, varying from 100 to 600 feet in width and a uniform depth of twenty feet below low water datum throughout the harbor.

The low water datum is 601.6 feet above mean tide level at New York.

The harbor frontage is owned as follows: 22 per cent by railroad companies, 77 per cent by private individuals, compa-

Duluth Boat Club



St. Louis County Court House, Duluth.

nies and corporations, and less than 1 per cent by municipalities.

There are ten railroads connecting with water terminals either directly or through affiliated lines; ten ore docks, aggregating 21,114 feet in length, with a total combined storage capacity of 980,700 gross tons; twenty-four coal docks, having combined storage capacity of 11,543,000 short tons.

There are twenty-five elevators in the harbor, in which were stored in 1919 36,325,000 bushels of grain. Twenty-three of these elevators are public, in the sense that they will handle grain for the public and are declared regular by the rules of the Board of Trade.

There are forty-three wharves handling freight other than iron ore, coal and grain.

The following statistics show the volume of tonnage during the season of 1919 for the Duluth-Superior harbor:

Total tons of freight received and shipped.........	42,895,681
Valuation of freight received and shipped.........	$444,037,628
Total number of boats arriving and departing......	9,135
Registered tonnage of same......................	32,883,529
Average tons of cargo received and shipped per day	178,758
Vessels enrolled and registered at Duluth.........	493

There are in Duluth fifty-six miles of paved streets, 210 miles of sewers, 405 acres of park, fourteen public playgrounds, twenty miles of boulevard. The boulevard system circles the brow of

Interstate Transfer Bridge, Minnesota Steel Co., New Duluth, Minn.

General view of Minnesota Steel Company's Plant, Duluth, Minn.

Fire Tug W. A. McGonagle.

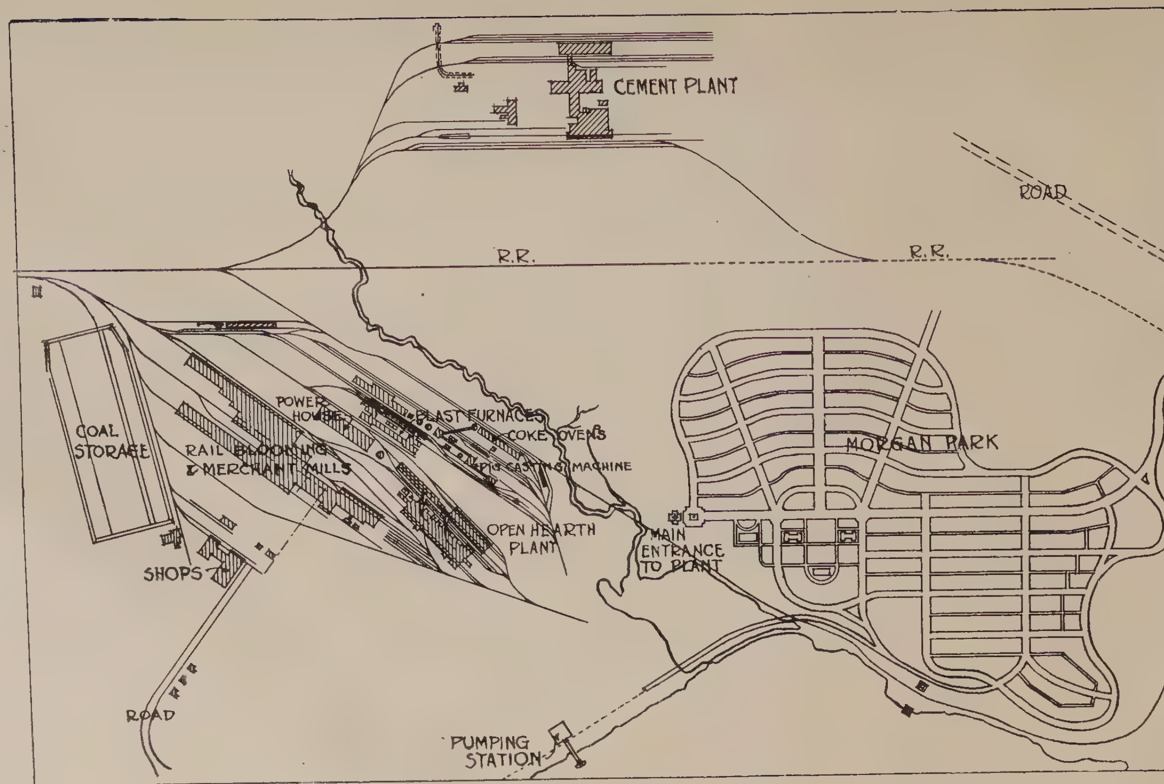
the hill upon which the city is built, following the shore line of an ancient beach at a height of from 450 to 600 feet above the lake. From it is obtained almost an aeroplane view of the city, the harbor and surrounding country, with here and there a view into the hillside parks, and deep glens with streams flowing through them.

There are in Duluth 191 manufacturing industries of various kinds. The following sketches briefly describe those that are of interest from an engineering standpoint.

The Minnesota Steel Company. Concrete block buildings, almost complete electrical drive, provisions for indefinite extensions and utilization of off-heat from its open hearth furnaces in boilers, are some of the features of the plant of the Minnesota Steel Company.

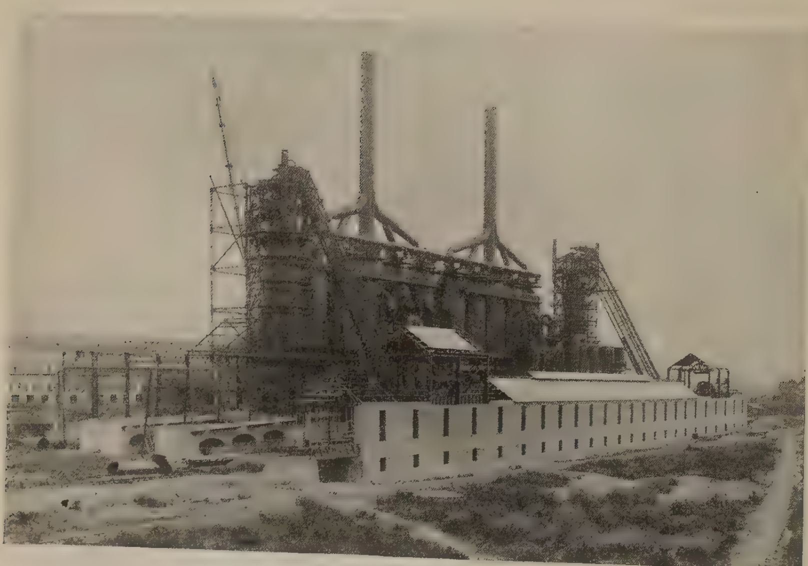
The plant is within the city limits of Duluth, nine miles from the Union Depot, on a tract of 1,500 acres, with two miles of water front on the St. Louis River, and connected with all railroads entering Duluth and Superior by the Spirit Lake Transfer Railway and Interstate Railway.

The plant includes two blast furnaces of 500 tons daily capacity. Each blast furnace is of the thin shelled water cooled type and is equipped with five stoves. Each stove is 22½ feet in diameter, 101 feet high, and contains 400,000 corrugated



MAP OF THE PLANT OF THE MINNESOTA STEEL COMPANY, TOWN SITE AND CEMENT PLANT

Furnaces of Minnesota Steel Company under construction.



Furnaces of Minnesota Steel Company, under construction.

checker brick. Gases from the blast furnace collected are passed through dust-catchers, grids and washers before delivery to the power house. There are ninety Koppers type by-product coke ovens and a benzol plant. Ten open hearth furnaces, with water-cooled buck-stays and posts, have a capacity of 100 tons each. Each furnace is equipped with a 437-h.p. vertical tube boiler, through which the hot gases from the furnace pass on the way to the stack. Steam is used principally in the forty-inch blooming mill and in the coke ovens. The boiler feed water from the exhaust steam from the blooming mill is heated by waste gases from the soaking pits, of which there are five.

There is one 28-inch finishing mill, one 16-inch continuous roughing train with 3-stand 12-inch finishing, 2-stand 10-inch finishing, and 2-stand 8-inch finishing.

The power house is 528 feet long and 110 feet wide and contains five blowing engines of from 20,000 to 28,000 cubic feet per minute, four generators of 3,000 k. w. capacity each, all gas driven; one 2,000 cubic foot air compressor, and three 750 k.w. rotary converters.

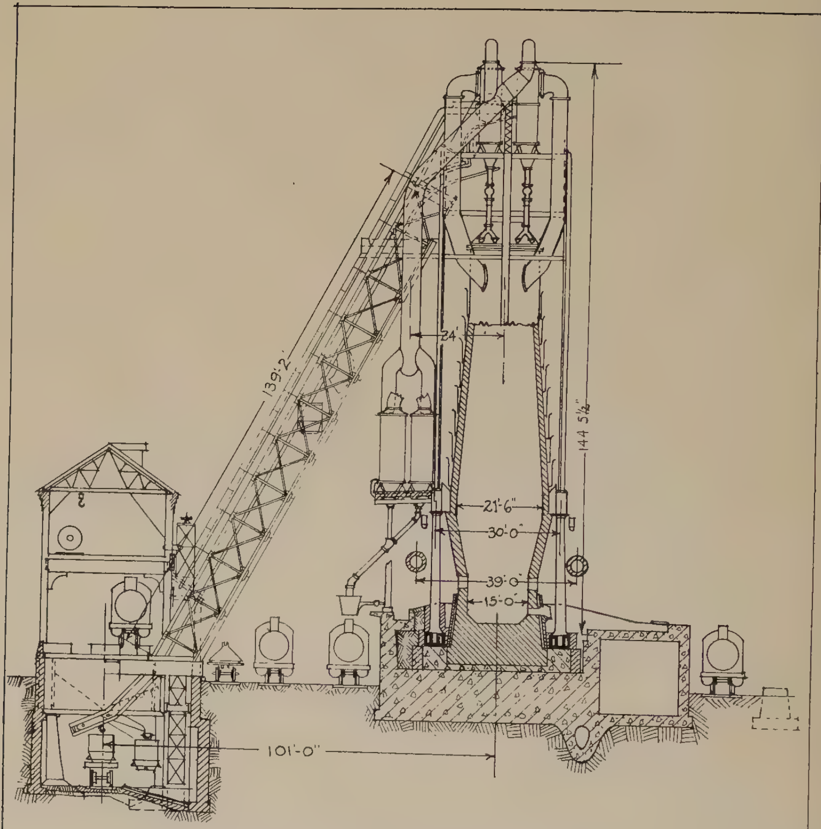
On account of the thin shelled furnaces it is highly important that there shall be no interruption in the water supply service, which is obtained from the St. Louis River, consequently the supply of electric power to 500-h.p. alternating current motors driving the 16-inch two stage pumps may be obtained from three different sources about the plant. The daily consumption of water is 65,000,000 gallons.

The pumps are installed in a 32x107-foot pit, 24 feet deep, so that the runners are submerged at least three feet, thus eliminating priming difficulties.

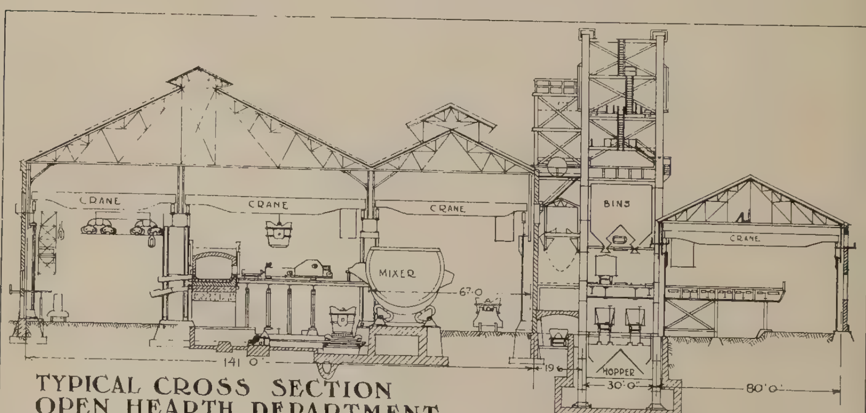
The drinking water supply is obtained from springs issuing from the bluff to the west of the plant.

The capacity of the plant is now 600,000 tons annually. Two thousand five hundred men are employed. There is also a cement plant in connection with the steel plant, producing 4,000 barrels of cement per day.

Several additions to the plant are under way. A new steam turbo generator power station of 15,000 k.w. is near completion. A rod and wire mill, equipped for producing barbed and woven wire fencing as well as nails, will be erected as soon as the material and labor situation will permit. Extensions to the ore, coal and stone storage yard are being made, and a plant for drying ammonium sulphate is being built.



CROSS-SECTION OF ONE OF THE BLAST FURNACES



TYPICAL CROSS SECTION
OPEN HEARTH DEPARTMENT

Morgan Park, sometimes called The Model City, is located near the plant, and is the last word in modern industrial housing. The houses are built of concrete blocks. Every facility for the welfare, health and happiness of the employees has been incorporated in this scheme. The result of this policy was reflected in the recent labor situation in the steel industry, in which trouble the employees of the Minnesota Steel Company did not join.

At this time there are 485 apartments complete and 250 under construction. There is also a magnificent club house, a modern school, churches, library and a general store.

Zenith Furnace Company. In 1903, an organization was perfected at Duluth, having for its primary motive the manufacture of Bessemer and foundry pig iron, for the purpose of supplying the trade tributary to the head of the lakes.

The most serious obstacle confronting the enterprise at its inception was the inability to obtain high grade coke at prices which were not prohibitive. Eventually this problem was solved satisfactorily by the installation of a battery of sixty-five by-product coke ovens. The daily consumption of this battery of ovens is about 600 tons of the highest quality of gas coal screenings, producing about 400 tons of coke for blast furnace use. The by-products are gas, which is supplied to the cities of Duluth and Superior for illuminating, cooking and heating purposes; tar, ammonia and motor fuel.

Only the highest grades of gas coal, mined in the Kentucky and Pittsburgh districts, are suitable for the production of Zenith coke. After the screenings are separated from the run of pile coal, which is received in cargo lots, the screened coal is sold to the steam and domestic trade in two sizes, known throughout the northwest under the names of Zenith Lump and Stove coal.

The company operates its own terminal railway in preference to depending upon the railroads for switching service.

The annual capacity of the Zenith Furnace Company now aggregates about 700,000 tons of coal, 125,000 tons of coke, 100,000 tons of pig iron, 1,000,000,000 cubic feet of gas, 1,000,000 pounds of ammonia, 2,000,000 gallons of tar and 350,000 gallons of motor fuel.

The Marshall-Wells Company represents one of the most remarkable commercial enterprises in the northwest territory, and

occupies a very unique and peculiar position whose influence is carried through their vast sales force, and resident representatives, to such far off points as Hawaiian Islands, New Zealand, Australia, Dutch East Indies, India, China, Japan, Alaska, and the furthermost parts of the provinces of Canada.

The Duluth institution is the parent house, with eight large branches, located at Winnipeg, Manitoba; Edmonton, Alberta; Vancouver, B. C.; Portland, Oregon; Spokane, Washington; warehouses at Great Falls and Billings, Montana, and at Aberdeen, Washington.

The Duluth institution was started in a very modest way about thirty years ago, and has reached its present magnitude through steady, persistent, efficient, serving growth.

The main building covers a space of 970 by 265, and contains an area of twenty-one acres of floor space crowded to the utmost with all manner of merchandise. The new iron and pipe building, which is one of the most modern in existence is equipped with five electric traveling cranes which take iron or steel from the boat dock, or from cars, and deposit it at any point within the building, or carry it to the wagon, truck or shipping floor.

Adjacent to and surrounding the main building are eight factory buildings engaged in the manufacture of various "Zenith" Brand of goods and materials.

The Marshall-Wells Company maintain a complete laboratory and testing department, where the specifications for all manner of edged tools are worked out, the finished product inspected before going to stock.

The oil testing laboratory in connection with the Dynamometer Station is continually engaged in the investigation, research and testing of motor lubricants. The blending station where "Zenoil" is fabricated, has at present a storage capacity of over 100,000 gallons of lubricating oil, and is being increased to a capacity of over 250,000 gallons at the present time.

Owing to the fact that the territories covered by the Marshall-Wells Company are particularly interesting to the mining engineers, so will the facilities of this company, to work hand in hand with them in furnishing mining materials and equipment appeal to them.

A cordial invitation is extended to all mining engineers and visitors to inspect the Marshall-Wells plant and equipment.

Great Northern Power Co. power-house at Thompson.

GREAT NORTHERN POWER COMPANY.

The Great Northern Power Company's hydro-electric station is located at Thomson, Minnesota, about 15 miles from Duluth. The St. Louis River (the source of power) has a total drainage area of 3,560 square miles. The normal precipitation is approximately 29.5 inches annually.

The normal flow of the St. Louis River is subject to extreme fluctuations, and in order to equalize it, storage reservoirs have been constructed as follows: Rice Lake, with a storage capacity of 25 square mile feet (1 square mile foot equals 27,878,400 cubic feet); Fish Lake, 50 square mile feet; Island Lake, 192 square mile feet; and Boulder Lake, 40 square mile feet, a total of 307 square mile feet.

Near Thomson the Company has a service reservoir formed by a reinforced concrete dam and spillway across the original river bed and smaller retaining dams.

Water is admitted through gate valves from the service reservoir to a canal 6,225 feet long, having an average cross section of 750 square feet. This canal terminates in a forebay from which individual 7-foot penstocks lead to the power station on the bank of the river. The average length of the penstocks is approximately 4,700 feet, of which the first 3,000 feet is built of California redwood, the balance being riveted steel. Water pressure at the turbines is regulated by a standpipe located on the hill immediately back of the power station, which is connected through a cross receiver to each penstock.

There are in the power station, 5 main generating units, all operating under an effective head of 350 feet at full load. The first three, completed in 1907, consist each of a 13,000 horse power Francis Type Allis Chalmers turbine, driving a 7,500 K. W. (normal rating) G. E. 25 cycle, 6,600 volt, 3-phase generator. The fourth unit, installed in 1914, consists of a 15,000 horse power Francis Type I. P. Morris turbine, driving a 12,000 K. V. A. maximum rated G. E. 25 cycle, 6,600 volt generator. The fifth unit, installed in 1919, consists of an I. P. Morris turbine, similar in capacity to the fourth unit, but driving a G. E. 60 cycle, 6,600 volt generator. Excitation is furnished by two impulse wheel-driven 125 volt 250 K. W. G. E. exciters and one 500 K. W. induction motor driven unit.

Power from the 25 cycle generator is stepped up to 33,000 volts, for transmission to Duluth, Minnesota, and Superior, Wisconsin, over three 3-phase circuits, two leading to Duluth and the third to Superior. Power from the 60 cycle unit is stepped up to 66,000 volts for transmission to the Mesaba Range over a single 3-phase line, 84 miles long. The distribution system on the Mesaba Range was originally supplied with power from a 60 cycle steam generating station at Virginia, Minnesota, having a total installed capacity of 6,000 K. V. A., now held in reserve for cases of failure of the transmission line and also to correct low voltage and power factor.

In Duluth and Superior 33,000 volt power is stepped down to 13,200 volts and distributed through underground and overhead circuits. At Hibbing the 60 cycle 66,000 volt energy transmitted from Thomson is stepped down to 22,000 volts and distributed between Biwabik on the East and Coleraine on the West.

Press of
Byron & Learned Company
Minneapolis

Date Due

Ja 21 '42			
APR 19 '49			
MAY 1 '51			